Workshop on Synthesis of JGOFS North Pacific Process Study

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JOINT GLOBAL OCEAN FLUX STUDY
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Foreword

This workshop is to be held to summarize and synthesize the results of the JGOFS North Pacific Process Study. As the JGOFS is approaching to end and the final Open Science Conference will be held in May 2003, the JGOFS North Pacific Synthesis Group is trying hard to materialize its synthesizing activity as selected presentations at the final Open Science Conference, and a special issue of Journal of Oceanography on the JGOFS North Pacific Synthesis. A compiled data set for the North Pacific as a legacy of JGOFS is also being planned.

This workshop is perhaps the first and the last international meeting for the synthesis of the JGOFS North Pacific, hence the conveners expect, as members of the NPSG, to obtain and share a view, from this workshop, on how the western subarctic North Pacific, the region of intensive study, is working in the global biogeochemical cycles of carbon and related elements.

This workshop consists of invited talks and posters. The invited speakers are expected to summarize and synthesize the current knowledge on his/her theme in the context of the objectives of the JGOFS North Pacific Process Study. The posters will give results of latest studies on JGOFS in the North Pacific, and the authors are expected to join and stimulate the discussion toward the synthesis. Chairpersons are responsible for stimulating and leading the discussion, and are expected to give summarizing talk at the general discussion. For this purpose, it would be helpful for all of the participants to have a look at the Terms of Reference to the North Pacific Process Study, and the objective Questions set by the North Pacific Task Team of JGOFS shown in the next page.

We thank Shizuo Tsunogai to provide the opportunity to have this workshop as a part of the SCOR/JOS international symposium on Our Oceanography toward the World Oceanography.

Toshiro Saino and Michio J. Kishi
Co-conveners

The Terms of Reference to the JGOFS North Pacific Task Team*
*Transformed into the North Pacific Synthesis Group, Oct. 2000.

The primary issues to be addressed by the North Pacific Task Team are the quantification of the biogeochemical cycles of carbon and associated elements in the North Pacific Ocean and its marginal seas.

Specific objectives are:

1) To assess the efficiency of physical and biological pumps, and their seasonal changes for different domains of the North Pacific and the adjacent marginal seas, including the effects of sea ice.

2) To study the formation and spreading of the intermediate water, and its implication for lateral flux of dissolved inorganic, dissolved organic and particulate matter.

3) To investigate and ultimately to enhance our understanding of air-sea fluxes of CO_2 and other atmospherically reactive gases that leads to predictions of the role of the North Pacific as a source and/or sink of CO_2 in collaboration with IGAC.

4) To understand the role of iron in maintaining the northern North Pacific as a high nutrient-low chlorophyll region.

5) To clarify the mechanism(s) controlling the transport of nutrients into the euphotic zone of the subtropical Pacific Ocean.

The objective questions, set by the NPTT, to be answered in the NPPS

\# What is the amount of CO_2 absorbed by the North Pacific Intermediate Water?

\# Does the amount vary with long-term, large scale physical forcing?

\# What is the amount of CO_2 absorbed by the biological pump?

\# What is the regional and temporal variability of the efficiency of the biological pump?

\# What controls the efficiency of the biological pump: Iron input, community structure of lower trophic level organisms?

\# Why do blooms occur in the western sub-arctic Pacific, not in the eastern sub-arctic Pacific?

Program

Workshop on Synthesis of JGOFS North Pacific Process Study

1 October (Tuesday) ---

13:30-13:35   Welcome, Scope of the Workshop

T. Saino

The Physical Pump of CO$_2$; Temporal and spatial variability
Chair: **Shuichi Watanabe (Japan Marine Science and Technology Ctr.)**

13:35-13:50   Extensive observation of sea surface pCO2 and chemical parameters by cargo ships covering the northern North Pacific since 1995

Yukihiro Nojiri, C. S. Wong, J. Zeng, S. Kariya,
K.Watanabe, H. Mukai, and Y. Fujinuma

13:50-14:05   Formation of Intermediate Water in the Okhotsk Sea: Results from CREST Wakatsuchi Project

Michiyo Yamamoto, Shuichi Watanabe, Shizuo Tsunogai, and
Masaaki Wakatsuchi

14:05-14:20   Formation and transport of North Pacific Intermediate Water (NPIW) as a shallow overturn in the Sub-arctic North Pacific: Results from the SAGE project.

Masao Fukasawa and the SAGE Group

14:20-14:35   The uptake rate of oceanic anthropogenic carbon in the North Pacific determined by DIC and CFC ages

Yutaka W. Watanabe and Tsuneo Ono

14:35-14:50   Discussion; achievements and future needs

14:50-15:45   Break & Posters

The Biological Pump; Temporal and spatial variability
Chair: **Atsushi Tsuda (National Fisheries Res. Ctr.)**

15:45-16:00   Seasonal and Interannual Variability of Chlorophyll *a* and Primary Productivity in the subarctic North Pacific as observed by satellite remote sensing.

Kosei Sasaoka, Sei-ichi Saitoh, and T. Saino

16:00-16:15   KNOT: Ocean time-series program in western North Pacific.

Nobuo Tsurushima, K. Imai, and Y. Nojiri

16:15-16:30   Plankton Dynamics and Biological Pump in the Oyashio Region: Overview of the A-line Monitoring

Hiroaki Saito and Atsushi Tsuda

16:30-16:45   Phytoplankton dynamics and iron limitation in the northwestern subarctic Pacific Ocean.

Hongbin Liu, K. Suzuki, and A. Tsuda

16:45-17:00   North Pacific East-West Similarities and Differences in Nutrient and Phytoplankton Dynamics

Paul J. Harrison

17:00-17:15   The Biological pump in the northwestern North Pacific

Makio C. Honda

17:15-17:30   Discussion; achievements and future needs

18:00-   Reception

2 October (Wednesday)--

Marginal Seas: Roles in the carbon cycle of the northern North Pacific

Chair: **Masashi Kusakabe (National Inst. Radiological Sciences)**

09:00-09:15   North Pacific Marginal Sea Exchanges of Carbon and Nutrients

Chen-Tung Arthur Chen

09:15-09:30   The biogeochemical cycle of CO_2 in the East/Japan Sea

Dong-Jin Kang and Kyung-Ryul Kim

09:30-09:45   Discussion; achievements and future needs

09:45-10:30   Break for Posters

Long-term variability; Is the North Pacific carbon cycle changing?

Chair: **Yasuhiro Yamanaka (Hokkaido U.)**

10:30-10:45   Decadal-scale oxygen changes in the upper thermocline of the Northeast Pacific: Ventilation or Productivity Change?

Steven Emerson, S. Mecking and J. Abell

10:45-11:00   Increased stratification and decreased primary productivity in the western subarctic North Pacific - a 30 years retrospective study-

Kazuaki Tadokoro, S. Chiba, T. Ono, and T. Saino

11:00-11:15   A 3-d model of the ocean carbon cycle: sensitivities to topographic mixing and the biological pump

Kenneth Denman and Konstantin Zahariev

11:15-11:30   Export and Sequestration of Particulate Organic Carbon in the North Pacific from Inverse Modeling.

Reiner Schilitzer

11:30-11:45   Discussion; achievements and future needs

General discussion

Chairs: **T. Saino and M.J. Kishi**

11:45-12:30   Chairpersons' comments and summary

12:30   Adjourn

JGOFS North Pacific Synthesis Group Meeting

2 October (Wednesday)---

<div align="right">Chair: **Alexander Bychkov**</div>

14:00-17:30   Closed, but guests are welcome. Please consult Alex Bychkov for attendance

Discussion Items: Presentation at the third JGOFS Open Science Conference
JO special issue on JGOFS North Pacific Synthesis
CD-ROM data from JGOFS North Pacific
JGOFS follow on in the North Pacific
Etc.

Abstracts of Talks

Extensive observation of sea surface pCO_2 and chemical parameters by cargo ships covering the northern North Pacific since 1995

Yukihiro Nojiri (NIES), C. S. Wong (IOS), Jiye Zeng (GEF), Shigeru Kariya (GEF), Koichi Watanabe (Toyama Pref. Univ.), Hitoshi Mukai (NIES), and Yasumi Fujinuma (NIES)

key words: North Pacific, ship-of-opportunity, atmosphere and ocean CO_2 monitoring

Monitoring of pCO_2 and ancillary measurement of biogeochemical parameters of surface seawater over the north Pacific by cargo ships has been continued since 1995 as a Japan-Canada corporative program between NIES and IOS. The first ship from March 1995 to September 1999 was M/S Skaugran of Seaboard Co., Canada, the second ship from November 1999 to May 2001 M/S Alligator Hope of MOL, Japan.

Setup of atmospheric and oceanic CO_2 monitoring by cargo ships in the North Pacific

Seawater measurement system was installed in the engine room and sea chest seawater line was blanched to the system, consisted from two different pCO_2 equilibrators, TS sensors and fluorescence monitor on board Skaugran (Murphy et al, 2001). The east-bound legs of Skaugran called port at several ports in the West Coast of US and Canada (Figure 1 left). The west-bound leg usually departed Vancouver and sailed the great circle route via Bering Sea. By the 4-year data set from Skaugran, we obtained monthly $DpCO_2$ maps in the north Pacific, north of 34°N.

In the case of M/S Alligator Hope, improved systems with two Tandem equilibrators for pCO_2 were installed in the fire pump room, near the ship bottom. The use two independent equilibrator and analyzer systems facilitated completely seamless logging of seawater pCO2 even when the CO_2 calibration gas ran. Independent continuous atmospheric CO_2 monitor was installed in the bow store, which substantially improved the performance of atmospheric CO_2 measurement. The on board LAN connection enabled to check the operating condition of seawater pCO_2 system from the radio room at the ship bridge. The ship route (Figure 1 right) was very regular departing Tokyo and arriving Seattle in east-bound legs and departing Vancouver and arriving Tokyo in west-bound legs.

In both cases, on board personnel took seawater samples, typically 3 or 4 samples per day, for on shore measurement of DIC, alkalinity, nutrients and chlorophyll-a (Wong et al., 2002). Typically crossing data for every 5-7 weeks interval have been obtained by M/S Skaugran and regular repeating track for every 5 weeks by M/S Alligator Hope.

Because of the changing ship route of M/S Alligator Hope, we moved the pCO_2 systems to the third volunteer ship, M/S Pyxis of Toyofuji Shipping Co., Japan. The atmospheric observation started from November 2001 and the seawater observation just started from July 2002. The on board system are very similar to M/S Alligator Hope but a single equilibrator pCO_2 system. M/S Pyxis usually departs Toyohashi, Japan and arrives Portland in east-bound leg and departs Long Beach and arrives Toyohashi in west-bound leg.

Data analysis of M/S Skaugran observation

The underway pCO_2 data during 68 crossings aboard M/S Skaugran between March 1995 and March 1999 were used for data analysis. Data collected by the US-Australia-Japan cruise and south of 34°N were excluded from this analysis. The mole fraction of CO_2 (xCO_2 in ppm) was measured every minute for seawater, and hourly for the air. The partial pressure of CO_2 (pCO_2 in µatm) in seawater was calculated from measured xCO_2 with warming corrections.

Table 1. Observation parameters of the NIES ship-of-opportunity program in the North Pacific since 1995

cargo ship	period	meteorology	atmosphere continuous	atmosphere discrete	seawater underway	seawater discrete
M/V Skaugran	1995 Mar. –1999 Sept.	wind velocity, wind direction air temperature humidity	CO_2 (hourly logging)	CO_2, CH_4, N_2O, aerosol	pCO_2 (logging at every minute), SST, salinity, fluorescence (1997–)	salinity, nutrients (NO_3, PO_4, Si), DIC, alkakinity, C^{13} in DIC, O^{18} in seawater, Chlorophyll-*a*, pigments
M/V Alligator Hope	1999 Nov. –2001 May	wind velocity, wind direction air temperature humidity solar radiation	CO_2 and O_3 (logging at every 10 seconds)	CO_2, CH_4, N_2O, C^{13} in CO_2, C^{14} in CO_2	pCO_2 (logging at every 10 seconds), SST, salinity, fluorescence	salinity, nutrients (NO_3, NO_2, NH_4, PO_4, Si), DIC, alkakinity, C^{13} in DIC, O^{18} in seawater, Chlorophyll-*a*
M/V Pyxis	2001 Nov.– (atmosphere) 2001 Jul.– (seawater)	wind velocity, wind direction air temperature humidity solar radiation	CO_2 and O_3 (logging at every 10 seconds)	CO_2, CH_4, N_2O, C^{13} in CO_2, C^{14} in CO_2, O_2/N_2 ratio	pCO_2 (logging at every 10 seconds), SST, salinity, fluorescence	salinity, nutrients (NO_3, NO_2, NH_4, PO_4, Si), DIC, alkakinity, C^{13} in DIC, O^{18} in seawater, Chlorophyll-*a*

The minute data were averaged into bins of 0.1-degree longitude for each crossing. Means for bins of 5-degree longitude between 145°E and 125°W were calculated from the 0.1-degree means. The seasonal change of ΔpCO₂ in each band in Figure 1 (left) was fitted by the function:

$$\Delta pCO_2(t) = a + b\sin(2pt) + c\cos(2pt) + d\sin(4pt) + e\cos(4pt)$$

where t is time in year. And then the monthly distribution maps of ΔpCO₂ were constructed. The air-sea flux of CO₂ was calculated based on the expression of Wanninkhof [1992], using wind data set from SSMI and ECMWF for the flux calculation.

The monthly distribution maps show clear unsynchronized patterns of ΔpCO₂ changes for different regions in the northern North Pacific. In winter (January to March), seawater pCO₂ in South Bering Sea, off Kamchatka island, and off Krill islands are higher than in the atmosphere (by up to 80 μatm) due to vertical mixing. In the rest of the NNP ΔpCO₂ is negative (up to 60 μatm), as a result of cooling. Starting in April, the reduction of dissolved inorganic carbon in seawater from photosynthesis causes large decreases of pCO₂ in the marginal regions (off Kuril Islands, South Bering Sea, and North American coast), up to 90 μatm near Alaskan Peninsula. The pCO₂ in the central basin gradually increases during spring, becoming nearly zero by June. During summer (July – September) the marginal region and South Bering Sea remain undersaturated. Undersaturation in the marginal regions decreases as warming continues. The central basin remains near equilibrium, although a region of significant oversaturation (up to 50 μatm) develops off the coast of North America and extending to approximately 155W to the west. In autumn, seawater pCO₂ decreases due to the cooling of sea surface waters, except for Bering Sea where vertical mixing starts as early as late October. A small region off Japan shows significant undersaturation (as low as –50 μatm) during this period. The remainder of the basin is undersaturated by 0 to 30 μatm.

CO₂ fluxes from this analysis were compared with fluxes computed from the global composite data set by Takahashi et al. (1997). Our pCO₂ grid data was adjusted to the 4 degree by 5 degree grid as same as that of Takahashi et al. (1997). Thus, fluxes for both studies were calculated using the same resolution of ΔpCO₂, wind speed, sea surface temperature, and salinity. The results of this comparison for monthly CO₂ fluxes are presented in Figure 2.
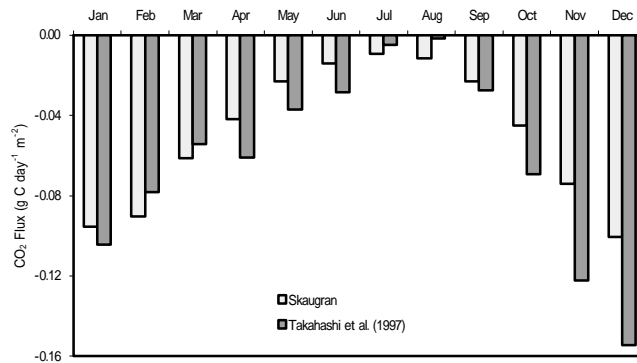
Both data sets show that the NNP is a CO₂ sink

Figure 2. Monthly comparison of net CO₂ flux (gCm⁻²day⁻¹) for the region of 34-53°N, 145°E-125°W. White bars for Skaugran 1995-1999 data set and striped bars for Takahashi et al. (1997) data set.

throughout the year, weakest in summer (July – September) and strongest in autumn (October – December). The monthly mean CO₂ flux ranges between –0.007 and –0.167 g C m⁻² day⁻¹, with negative sign indicating ocean uptake. Comparison of monthly mean fluxes for the NNP indicates that in spring and autumn, monthly fluxes estimated from ΔpCO₂ of Takahashi et al. (1997) are systematically more negative than those estimated from our analysis.

Based on our ΔpCO₂, we estimate that the region is a small sink for carbon (–0.26 Gt C yr⁻¹) with ECMWF wind field. This value is the result of integration of fluxes over the monitored area, north of 34°N in the north Pacific. In comparison, the integrated net annual flux using the data of Takahashi et al. is –0.33 Gt C yr⁻¹, suggesting 27% more uptake on an annual basis. In case SSMI wind field was used for our pCO₂ field, the flux was –0.24 Gt C yr⁻¹.

Status of the NIES north Pacific CO₂ monitoring data set

The M/S Skaugran monitoring was completed in September 1999. The examined data set have been opened in a web page (http://www.mirc.jha.or.jp/nies/SK/), including SST, SSS, pCO₂. The surface nutrient data set from discrete sampling have already been examined and will be added soon.

The M/S Alligator Hope monitoring also completed in May 2001. The data web site has been prepared at http://www.mirc.jha.or.jp/nies/AH/.

Figure 1 Cruise tracks of underway pCO₂ observation by ships-of-opportunity in NIES/IOS joint monitoring program, left: M/S Skaugran for 1995-1999, right: M/S Alligator Hope for 1999-2001
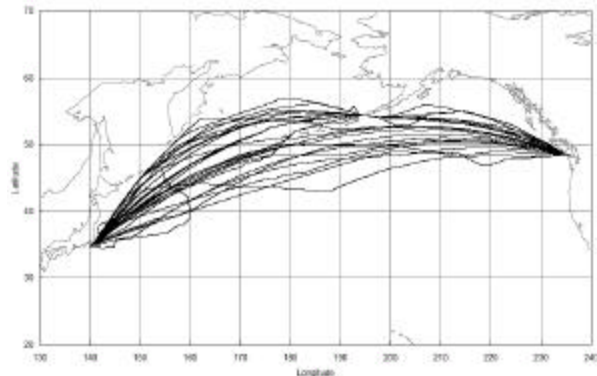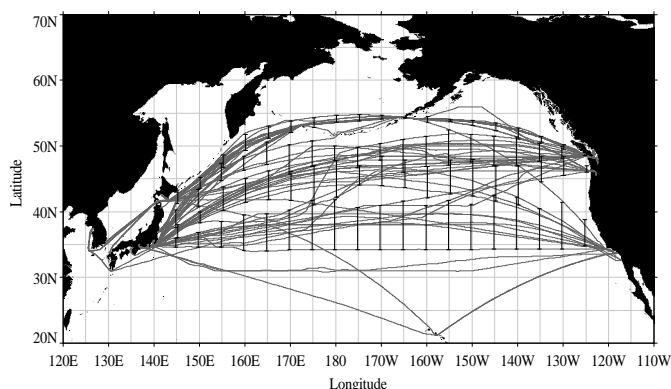
Formation of Intermediate Water in the Okhotsk Sea: Results from CREST Wakatsuchi Project

Michiyo Yamamoto[1], Shuichi Watanabe[2], Shizuo Tsunogai, and Masaaki Wakatsuchi[3]
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Keywords: chemical tracers, Okhotsk Sea Intermediate Water, formation rate

Introduction

The cold, less saline, and oxygenated Okhotsk Sea Intermediate Water (OSIW, $26.8<$ <27.4) appears to be a source of the North Pacific Intermediate Water (NPIW). To clarify the role of the Okhotsk Sea in the NPIW, the formation processes of the OSIW were studied with chemical tracers such as $\delta^{18}O$ and CFCs.

Sampling and Measurements

Samples were collected in the northern and western part of the Okhotsk Sea during the joint Okhotsk Sea cruise, with the research vessel *professor Khromov*, from 1998 to 2000. The $\delta^{18}O$ was measured by a mass spectrometer with a precision about 0.02‰. The CFCs (CFC-11 and CFC-12) concentration was measured with ECD-GC on board. Precision from replicate samples was lower than 2%.

Results and Discussion

The cold and high-CFCs water existing on the northern continental shelf was dense enough to enter the intermediate layer. The relationship between $\delta^{18}O$ and salinity of this water shows that it includes brine rejected during sea ice formation. By using the $\delta^{18}O$ and salinity relation, we can trace this water. The dense shelf water seems to mix with the surrounding water very well during its southward flow (Fig. 1). The mean fraction of the dense shelf water in the OSIW at $=26.8$ level was estimated to be 23%. This is smaller than previous estimates based on an assumption that OSIW is a mixture of dense shelf water and Pacific water on the isopycnal surfaces. To produce T and S properties of the OSIW diapycnal mixing with upper and lower layer waters is needed. The pCFCs distribution showed that diapycnal mixing

occurs around the Kuril Straits and near continental slope. It must affects on the OSIW. Thus we tried to quantify effects of dense shelf water and diapycnal mixing on the OSIW. The result suggested that T, S properties of the OSIW is mainly produced by diapycnal mixing, rather than mixing with the dense shelf water.

A simple box model constrained by CFCs concentrations was constructed to estimate the formation rate of the OSIW. This model includes diapycnal mixing process. The calculated formation rate was 4.4Sv from CFC-11, and 5.4Sv from CFC-12. The renewal time of the OSIW is estimated to be about 4years.
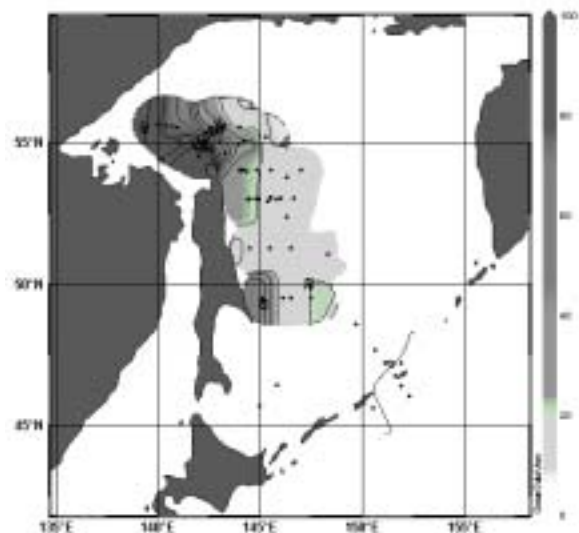

Figure 1. Fraction (%) of the dense shelf water in the OSIW on the density surface of 26.8 .

Formation and transport of North Pacific Intermediate Water (NPIW) as a shallow overturn in the Sub-arctic North Pacific: Results from the SAGE project.

Masao Fukasawa[1] and SAGE group

1 Japan Marine Science and Technology Center

An ocean science program of SAGE, Sub-Arctic Gyre Experiment, was carried out from 1997 through 2001 under a fund from Science and Technology Agency Japan. The program of SAGE included physical, chemical and biogeochemical oceanographic studies. Its main goal was set to identify the location and the amount and/or the strength of the overturn in the sub-arctic North Pacific (SANP). It has been well known that the shallow overturn in SANP leads to the NPIW formation, which transports fresh water and carbon dioxide in near surface waters to southeastward across the boundary between Sub-Arctic Gyre and the Sub-Tropical Gyre. However, the physical process of the formation, the mass transport (including carbon dioxide) of the NPIW was not clear in spite of that numbers of studies have been focused their attention on these problems.

SAGE carried out tens of new hydrographic observation cruises in the SANP including re-visits of WHP P1 and P17N with carbon measurements. Also, numerical models for the formation and spreading processes of water masses in SAGE area were constructed.

The main results of SAGE on the sub-arctic gyre structure and NPIW formation can be highlighted as follows;

1. A new flow path of Western Sub-Arctic Water (WSAW), which takes the form of the dicho-thermal layers, were found along the eastern periphery of the western gyre.

2. Intrusion of meso-thermal water beneath the dicho-thermal water, which leads to a substantial shallow overturn in the sub-arctic North Pacific, seems to take place through three branches.

3. A total of 9 Sv of the original NPIW flow southward off Honshu. Out of them, only 6 Sv is fed into the Perturbed Region, and 3 Sv of the original NPIW is recirculated into the sub-arctic gyre.

4. 0.025Gt/y of anthropogenic carbon is transported into the inter-mediate layer of the sub-tropical gyre.

The uptake rate of oceanic anthropogenic carbon in the North Pacific determined by DIC and CFC ages

Yutaka W. Watanabe (Hokkaido Univ.), Tsuneo Ono (National Fisheries Res. Institute)

When considering the present balance of anthropogenic carbon, it is necessary to determine how much of the anthropogenically produced carbon the ocean absorbs and where the carbon accumulates in the ocean. The spatial distribution of anthropogenic carbon, although estimated by various recent models, show that both the inventory and uptake rate differ significantly between models. Thus it is difficult to know the reliability of the results (e.g., Sarmiento et al. 1992). On the other hand, new observational data-based approaches, like the direct DIC comparison approach (e.g., Ono et al., 1998; Sabine et al., 1999) and C-13 approach (Quay et al., 1992) during any decadal intervals, have been proposed. Unfortunately, at present, these approaches are limited in use due to the insufficient quality of the historical data and also the insufficient spatial distribution of the data available, which can be partially overcome using multiple regression techniques (Slansky et al., 1997), Overall, these methods can only give a rough estimate with a large potential error.

We here proposed an approach to estimate the rate of increase of the oceanic anthropogenic carbon inventory with the CFC dating technique. This approach relies on the elapsed time from when the water lost contact with atmosphere as determined by CFC tracer age. Furthermore, the assumption is made that it remains constant over a decadal time scale. Finally, we consider only the increase in anthropogenic carbon from one decade to another and not the entire change from the pre-industrial period to the present. Our indirect method agreed with the direct DIC comparison method's results within the uncertainty of $0.12\ \mu mol\ kg^{-1}\ yr^{-1}$. Using this approach to 25000 bottle data sets, the spatial distributions of the rate of increase of the anthropogenic carbon inventory, and the uptake rate of anthropogenic carbon in the Pacific south of 60 °S were obtained.

The western North Pacific subtropical region exhibited a maximum in the rate of increase of the anthropogenic carbon inventory of more than 8 g C $m^{-2}\ yr^{-1}$ during the 1990s, which was equivalent to 34 % of the total uptake rate in the entire North Pacific. The net total uptake rate of anthropogenic carbon was 0.54 ± 0.02 Pg C yr^{-1} during the 1990s in the whole North Pacific. The uptake rate in the whole South Pacific south of 60 °S was also estimated to be 0.78 ± 0.02 Pg C yr^{-1}. These estimations indicated that the Pacific absorbs 1.32 ± 0.02 Pg C yr^{-1} which was 57% of the whole oceanic uptake of anthropogenic carbon during the 1990s. However, it is possible that the recent oceanic conditions have changed due to the artificial greenhouse warming effects and/or the natural climate change. Thus it would be necessary to reevaluate the anthropogenic carbon input from the preindustrial period to the present in the future.
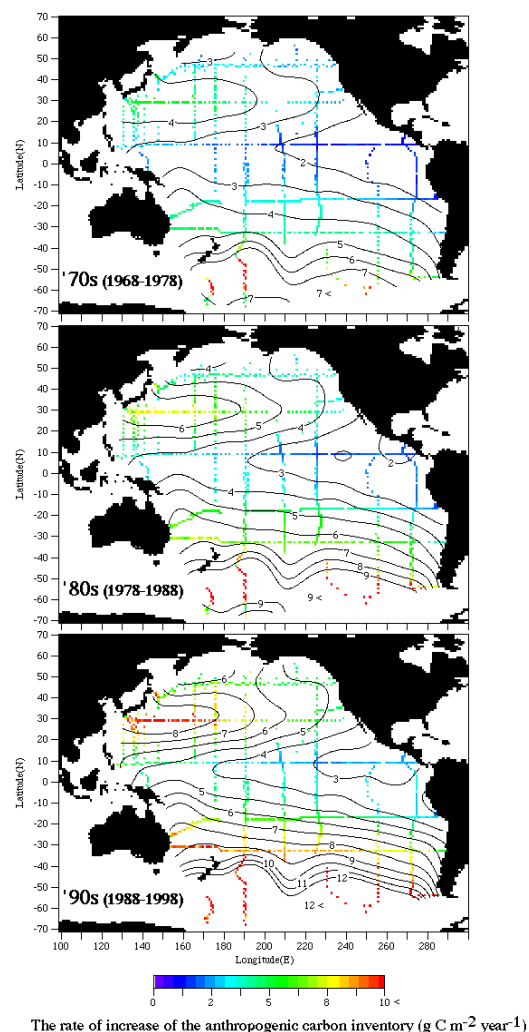
The rate of increase of the anthropogenic carbon inventory (g C m^{-2} year^{-1})

Seasonal and interannual variability of chlorophyll *a* and primary productivity in the subarctic north Pacific as observed by satellite remote sensing

Kosei Sasaoka[1], Sei-ichi Saitoh[2], and Toshiro Saino[3, 1]

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[3]Hydrospheric Atomospheric Research Center, Nagoya University

The North Pacific can be viewed as a large estuary in which a strong halocline at 100-120 meters depth separates the surface from the deeper waters. Nutrient concentrations in deep waters are the highest in the global ocean because it is the terminal region for the abyssal circulation. High primary productivity and strong air-sea interactions characterize the carbon cycle of this region. Also known is that this region is one of the High Nutrients Low Chlorophyll regions. A preliminary observation by the CZCS revealed significant east-west gradient in the distribution of chlorophyll *a* (chl-*a*), and the blooms in spring appeared only in the western region of the subarctic North Pacific.

As a part of the JGOFS North Pacific Process Study we studied seasonal and interannual variabilities of the distributions of chl-*a* and primary productivity utilizing a combination of satellite remote sensing data as well as climatology data. Emphasis was placed on understanding the east-west difference of the variability, and the effect of large scale climatic variability such as ENSO and/or monsoonal wind in relation to conditions of Aleutian Low Pressure System.

Remotely sensed data from multi sensors, including ocean color (OCTS and SeaWiFS), sea surface temperature (SST, AVHRR), wind (SSM/I) and photosynthetically available radiation (PAR, SeaWiFS) datasets were utilized for the purpose of this study. Time series data of primary productivity on a monthly time scale were computed using the VGPM (Beherenfeld and Falkowski, 1997). To help understanding the regulatory mechanism of chl-*a* and primary productivity distributions, calculation was made for sea surface nitrate using SST and chl-*a* data (Goes et al,. 1999, 2000).

Ocean color imagery clearly showed seasonal and interannual variability in the spatial abundance and distribution of chl-*a* and primary productivity in the study area. Magnitude of chl-*a* seasonal variability at WSG (Western subarctic Gyre, near the 50N, 165E) is greater than that at AG (Alaska Gyre, near the 50N, 145W). Ranges of chl-*a* concentrations at WSG were about 0.2-1.1 mgm^{-3} throughout the year, and a few peaks (about 1.0 mgm^{-3}) were seen in spring and fall bloom periods. Chl-*a* concentrations at AG were generally low (0.2-0.7 mgm^{-3}), and no bloom was observed. Contrary to this, ranges of primary productivity were similar in the west (100-1100 mgCm^{-2}Day^{-1} at WSG) and the east (130-1100 mgCm^{-2}Day^{-1} at AG), and the seasonal variability of primary productivity was similar in both regions, where one single peak was seen in summer (July or August).

A large interannual variability of chl-*a* and primary productivity coincided with the 1997/1998 El Nĭno and 1998/1999 La Nĭna events. In summer to fall 1998, Chl-*a* and primary productivity at WSG were remarkably high (about 0.9 mgm^{-3} and 1038 mgCm^{-2}Day^{-1}) compared with those in the same season of the other years. Coincidentally, chl-*a* and primary productivity at AG in summer to fall 1998 (about 0.3 mgm^{-3} and 590 mgCm^{-2}day^{-1}) were lower than those in other years. It appeared that high chl-*a* at WSG corresponded to the warmer SST and low chl-*a* at AG corresponded to cooler SST. We suggest, based on the multi-sensor satellite data, that the high chl-*a* around the WSG from summer to fall in 1998 was resulted from combination of; 1) larger nutrients inputs in winter, 2) stronger wind in spring to summer causing light limitation of phytoplankton growth, 3) higher PAR in summer, and 4) warmer surface waters in fall compared with the normal years.

Further discussion will be made on the east-west differences in distribution patterns of chl-*a* and primary productivity, and their controlling factor in the subarctic North Pacific in relation to ENSO events.

KNOT : Ocean time-series program in western North Pacific

Nobuo Tsurushima[1, 2], Keiri Imai[2, 3], and Yukihiro Nojiri[3, 2]
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Keywords   time-series observation, western North Pacific, carbon cycle, primary productivity

In June 1998, Japanese ocean scientists established a time-series observation station in the western North Pacific. The station, located at 44°N, 155°E, is known as KNOT, short for *Kyodo* North Pacific Ocean Time-series (Kyodo is a Japanese word meaning "collaborative"). The scientific focus of the program at KNOT is the seasonal carbon cycle. The KNOT program was proposed by the JGOFS-Japan committee. It is funded by the Japan Science and Technology Corporation (JST).

The KNOT station was occupied 27 times from June 1998 to October 2000. Four research vessels have been used for the observations made to date: T/S *Hokusei-maru* (Hokkaido Univ.), R/V *Bosei-maru* (Tokai Univ.), R/V *Mirai* (JAMSTEC) and R/V *Hakuho* (Univ. of Tokyo). Measurements made during KNOT include carbonate system parameters, including dissolved inorganic carbon (DIC), alkalinity and the fugacity of carbon dioxide (fCO_2) in surface waters, as well as temperature, salinity, nutrients and oxygen. Surface layer measurements of biological activity, including chlorophyll *a* concentrations and primary productivity, were also made on nearly every cruise, along with collections of phyto- and zoo-plankton. For more than half the cruises, floating sediment traps were deployed, and measurements were made of particulate and dissolved organic carbon (POC and DOC), iron, trace metals, halocarbons, methane, nitrous oxide, $^{13}CO_2$, $N_2/O_2/Ar$, and thorium-234.

Large seasonal variations in surface chemical and biological parameters occur at the KNOT station. Observed seasonal variations in surface seawater nutrients and DIC at KNOT were larger than those observed at the Hawaii Ocean Time-series (HOT) station, the Bermuda Atlantic Time-series Study (BATS) station, or Ocean Station Papa (OSP) in the subarctic eastern North Pacific. The seasonal amplitude of DIC at KNOT was more than 100 micromoles per kilogram (Fig. 1), largely because of biological uptake in summer and strong vertical mixing in winter. As a result of these large DIC changes, surface water fCO_2 was lower than the atmospheric value in summer and autumn, and oceanic uptake of CO_2 was largest in autumn when the wind velocity starts to increase. Primary productivity was highest in May, principally because of diatom production. Although the primary productivity had a distinct seasonal variation, with a 10-fold change during the winter and spring, the light utilization index (the ratio of chlorophyll a specific productivity to PAR) was constant in all seasons.   Although the surface nutrient and DIC variability were higher at station KNOT than those at OSP, primary productivity and estimated new production were not higher. This may be a result of the lower regenerated production and shallower summer mixed layer in the western subarctic North Pacific. When the data on water column DOC and POC and the sinking flux of POC are available, we will be able to describe more precisely the carbon cycle at station KNOT.
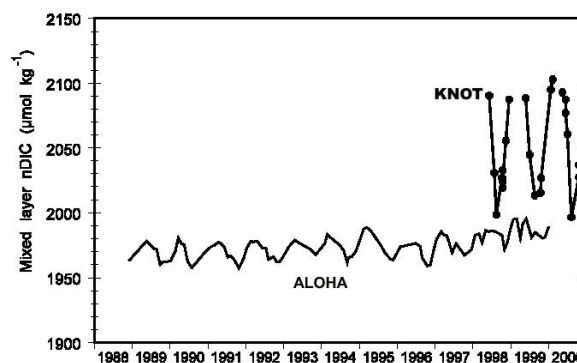

Figure 1. Comparison of mixed-layer dissolved inorganic carbon (DIC) concentration at station KNOT (1998 to 2000, normalized to salinity 33) and HOT station ALOHA (1988 to 1999, normalized to salinity 35).

Plankton Dynamics and Biological Pump in the Oyashio Region: Overview of the *A-line* Monitoring

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Oyashio region is the westernmost part of the Western Subarctic Gyre. Different from the other regions of the subarctic Pacific, high chlorophyll concentration is observed in spring and nitrate is depleted in summer. The *A-line*, crossing the Oyashio current in a SSE direction from Akkeshi Bay, Hokkaido, was at first established to monitor physical characteristics of the Oyashio in 1987. From 1990, biological observations were reinforced in the monitoring, and 6-8 cruises per year have been carried out.

The Oyashio ecosystem is characterized by a large annual variation in nutrient concentration and plankton biomass. Diatoms form a phytoplankton bloom in spring and consume both nitrate and silicic acid supplied to the surface mixed layer by the winter mixing. Seasonal variations in sea-surface nitrate and silicic acid concentration were 19.2 ± 1.7 and $29.3+4.1$ mmol m^{-3}, respectively. The consumption ratio of silicic acid to nitrate increased from 1.26 at early spring to 2.59 at mid-bloom period. Such a change in the consumption ratio is estimated to be due to the growth stress of diatom with developing the spring bloom. The spring bloom finished by June-July. At the end of the spring bloom, macronutrient concentrations were usually higher than reported half-saturation uptake constants, indicating that the termination of the spring bloom was dependent on the other factors than macronutrient depletion. After the termination of the spring bloom, macronutrients decreased gradually and nitrate was depleted until August. The HNLC region of the subarctic Pacific extends to the Oyashio region in this transition period between the termination of the spring bloom (May-June) and August. Fall phytoplankton bloom was occasionally observed at a part of the Oyashio region and the magnitude of the bloom was smaller than one in the spring.

Sediment trap detected large flux of biogenic matter during spring to early summer. The silica flux reached 77 % of the mass flux indicating the important role of diatom in the biological pump. Organic-C/Inorganic-C ratio was always higher than 0.7 and the mean was 5.1. The vertical carbon transport by ontogenetically migrating copepods, e.g., three species of *Neocalanus, Eucalanus bungii,* is not detected by means of sediment trap. The calculated carbon transport to 1000 m by these species was 5.0 gC m^{-2} year^{-1}, which was 107 % of one detected by sediment trap. The role of these copepods in the biological pump is quite important in the Oyashio region.

Phytoplankton dynamics and iron limitation in the northwestern subarctic Pacific Ocean

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Based on published literatures and results of a recent *in situ* iron enrichment experiment in the northwestern subarctic Pacific, we have reached the following conclusions.

1) Phytoplankton community in the western subarctic Pacific is composed mostly of pico- and nanophytoplankton. Chlorophyll *a* in the < 2µm size fraction accounted for more than half of the total chlorophyll *a* in all seasons, with higher contributions of up to 75% of the total chlorophyll *a* in summer and fall. In contrast, chlorophyll *a* in the > 10 µm fraction, mainly diatoms, was always < 10% of the total chlorophyll *a*, except during occasional spring bloom period.

2) Among picophytoplankton, eukaryotic picoplankton dominates throughout the year. Average ratio of prokaryotes (*Synechococcus*) to eukaryotes is 1:6.8 at Stn.KNOT during the first two years of the observation.

3) There is not a clear seasonal variation in chlorophyll *a* concentration, except a slightly higher value observed in spring and fall. Annual variation of integrated chlorophyll *a* concentration was less than 3 fold. In contrast, primary production varied 10 fold. It is suggested that light is the main factor that controls the primary productivity in the northwestern subarctic Pacific.

4) Contrasting to the lack of clear seasonal variation in total chlorophyll *a*, there is a pattern of species succession in phytoplankton community. At Stn.KNOT, diatoms abundance peaked in May, followed by picoeukaryotes and *Synechococcus* in the summer.

5) Based on the results from iron enrichment experiments, it is clear that the growth of phytoplankton (especially > 10 µm phytoplankton) in the western subarctic Pacific is limited by iron bioavailability. In an *in situ* iron enrichment experiment conducted in the Western Subarctic Gyre (WSG) last summer, ambient dissolved iron concentrations in the surface water was as low as that in the AG. Photosynthetic competence (F_v/F_m) of surface phytoplankton was remarkably improved after a Fe addition, and surface chlorophyll *a* concentration increased from <1 to ca. 20 µg/L. The micro-sized chlorophyll *a* (>10 µm) increased ca. 50 folder after iron addition and the dominant microphytoplankton in the iron-enriched patch changed from pennate diatoms to a chain-forming centric diatom, *Chaetoceros debilis*.

6) Microzooplankton grazing rate in the WSG is approximately equal to phytoplankton growth in normal condition, but fall short to consume all phytoplankton growth when iron was added. Mesozooplankton grazing in the WSG is unknown, but recent study in the Alaska Gyre suggests that they are able to keep microphytoplankton biomass at low level under normal condition.

7) Thus, we conclude that the phytoplankton growth in the WSG is mainly limited by iron, with light limitation occurred in winter. Under low iron concentration, phytoplankton community is dominated by pico- and nanophytoplankton, which are less sensitive to iron limitation and controlled by microzooplankton grazing. Compare to other HNLC regions, iron limitation in the WSG is less severe due to its closeness to the Asia desert dust source that is the main supply of atmospheric iron deposit. However, because of relatively mild iron stress, phytoplankton response to sporadic iron supply is quicker and stronger because the seeds of high iron-requiring fast-growing diatoms are readily present.

North Pacific East-West Similarities and Differences in Nutrient and Phytoplankton Dynamics

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The NE and NW subarctic Pacific Gyres (SWG and SEG) have many similarities. In both gyres, macronutrients are high and chl is low, and hence both gyres are HNLC regions. Most of the chl is in the small size fraction (< 5 μm) and is dominated by prymnesiophytes and prasinophytes. Diatoms normally make up only a very small fraction of the chl ($< 10\%$). There is little seasonality in chl and the annual variation is 2 to 3 times. Primary productivity shows more seasonal variation (from 5 to 10 times). The mean daily productivity is remarkably similar for both gyres (650-750 mg C m^{-2} d^{-1}). Primary productivity is limited by iron in late spring-summer and by a combination of light and iron in the winter. When iron is added, large (> 10 μm) diatoms grow up, indicating that they were initially iron-limited. There is little or no increase in the smaller eukaryotes and their biomass appears to be controlled by grazing of microzooplankton and possibly mild iron limitation. These small cells which are normally the most abundant, utilize regenerated nitrogen produced by the micrograzers. Hence, the f-ratio is low (0.25) and does not vary seasonally. Therefore, top down control is exerted by the micrograzers on the small cells, while there is bottom up control of the large phytoplankton due to low iron concentrations.

Despite the general similarities (e.g. both are HNLC regions) in the WSG and the SEG, there are many important differences. The SWG has higher nutrient concentrations (e.g. nitrate ranges from 10-23 μM and silicate ranges from 10-40 μM in the SWG vs 6-17 μM for nitrate and 8-22 μM for silicate in the SEG). Iron concentrations are higher in the SWG vs the SEG, probably due to the closer proximity to the source of dust from the Gobi Desert. The photic zone is shallower in the SWG (mean photic zone depth for the SWG is 37 m vs 62 m for the SEG). The summer mixed layer is usually shallower (20-50 m vs 10-60 m). While chl concentrations are low in both gyres, chl in the WSG is about two times higher (0.5-1.5 vs 0.3-0.5 μg L^{-1}). In contrast, summer primary productivity is similar (~ 600 mg C m^{-2} d^{-1}). Iron enrichment experiments demonstrated clear iron limitation in both gyres, however centric diatoms (*Thalassiosira* in an Oct experiment and *Chaetoceros debilis* in a July *in situ* iron addition) became dominant in the SWG, compared to pennate diatoms (*Pseudonitzschia* sp.) becoming dominant in the SEG.

A comparison between these two similar gyres with important differences provides valuable insights into factors controlling primary productivity. In particular, these two gyres serve as valuable field sites to study the iron gradient hypothesis and the response of the ecosystem to this iron gradient. Further more, the SWG is ideally situated to document the response of the ecosystem to a natural dust event in April-May.

The Biological pump in the northwestern North Pacific

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It has been considered that the northwestern North Pacific is one of productive areas in the global ocean. Although the marginal zones along Japan Island, Kuril islands, Kamchutska peninsula and Aleutian islands is certainly productive, the recent study does not always show the high primary production in the Western Subarctic Gyre (WSG). In addition, the recent analysis pointed out that the vertical change in the carbon flux in the WSG is large unlike the previous reports. The superior point of the biological pump for the uptake of atmospheric CO_2 in the northwestern North Pacific is that the ratio of organic carbon flux to inorganic carbon flux, the export flux and export ratio out of the surface water are higher than other global oceans. This presentation is a review on the biological pump in the northwestern North Pacific.

1. Carbon flux at the deep sea

Honda (2001) compiled the sediment trap data in the global ocean and compared the total carbon flux and organic carbon flux in the northwestern North Pacific with those in other oceans. He estimated that the annual mean of the total carbon flux at 1000 m ranges from approximately 7 to 23 mg m^{-2} day^{-1}. The total carbon flux in the northwestern North Pacific including the Sea of Okhotsk and the Bering Sea is approximately 17 mg m^{-2} day^{-1} and the second largest following the Arabian Sea (23 mg m^{-2} day^{-1}). However the organic carbon flux at 1000 m of approximately 13 mg m^{-2} day^{-1} is the largest in the global ocean, while inorganic carbon flux is the largest in the Arabian Sea followed by the middle North Atlantic.

2. The ratio of organic carbon and inorganic carbon

The ratio of organic carbon to inorganic carbon (C$_{org}$ / C$_{inorg}$ ratio) is important for the quantification of the efficiency of the biological pump for the drawdown of atmospheric CO_2. Tsunogai and Noriki (1991) summarized sediment trap data in the global ocean and concluded that the ocean's biological activity plays a role in the sink of atmospheric CO_2 because the C$_{org}$ / C$_{inorg}$ ratios of sediment trap samples are on global average higher than 1. The C$_{org}$ / C$_{inorg}$ ratio of sediment trap sample in the northwestern North Pacific is estimated to be approximately 4 and the second largest following 7 for the southern ocean. Contrast to the large total carbon flux, the C$_{org}$ / C$_{inorg}$ ratio in the Arabian Sea is low (1.3). This ratio correlates positively with the ratio of opal flux to $CaCO_3$ flux (Si / Ca). It is indicative of that the efficiency of the biological pump for the uptake of the atmospheric CO_2 is high in the area where diatom is pre-dominant. Honda et al. (1997) and Honda (2001) estimated the ability of biological pump in the drawdown of pCO_2 in the surface water with using organic carbon and inorganic carbon fluxes collected by the sediment trap and the empirical equation for the vertical change in carbon fluxes. As a result, the biological pump in the northwestern North Pacific and the Antarctic Ocean works more efficiently for the uptake of atmospheric CO_2 than other oceans.

3. Primary production

In general, the northwestern North Pacific has been characterized as the highly productive region attributed to the high nutrient supply by the aged deep water invasion. During the spring bloom, the high primary productions of 1000 – 2000 mg m^{-2} day^{-1} were measured by the ^{14}C or ^{13}C method (Taniguchi and Kawamura, 1972; Maita and Odate, 1988, Hama et al., 1993; Shiomoto, 2000a, b). However the recent measurement did not show such a high primary production in the WSG. According to seasonal variability in the primary production in the WSG (Shiomoto, 2000 a, b), the primary production in spring, summer, autumn and winter were estimated to be 318 ± 55, 247 ± 177, 191 ± 57, and 40 ± 36 mg-C m^{-2} day^{-1}, respectively, and the annual average is 199 mg-C m^{-2} day^{-1}. Imai et al. (2002) measured the primary production at station KNOT as a part of JGOFS North Pacific Process Study. Based on their result, the annual average can be estimated to be approximately 220 mg-C m^{-2} day^{-1}. This value is smaller than those at the subtropical time-series stations HOT and BATS (Karl et al., 2001). As shown in remotely sensed ocean color data, the primary production in the coastal regions of the northwestern North Pacific and during the spring bloom are significantly higher than that of global average. However the general aspect of the primary production in the WSG might not be so high.

4. Export flux

In the consideration of the biological pump, one of important issues is the export flux that is the organic carbon flux out of the euphotic layer or the winter mixed layer. Harada et al. (2001) estimated the export flux by [234]Th method at station KNOT. Although there are some controversial points such as the ratio of fluxes of particulate organic carbon (POC) to [234]Th and assumption of the steady state, they reported the export fluxes at 200 m in the spring and the winter are 6 mmol m^{-2} day^{-1} and 9 mmol m^{-2} day^{-1}, respectively. Assuming that the average of these is the annual average of the export flux, the annual average is estimated to be approximately 7.5 mmol m^{-2} day^{-1} or 90 mg m^{-2} day^{-1} at station KNOT.

The export flux has been also estimated by the difference in the total amount of total dissolved carbon or nutrients between winter and summer in the mixed layer. The export flux estimated by this method is referred to as the "net community production" (NCP) or the "new production" (Codispoti et al., 1986; Minas et al., 1986). Using the difference in the integrated nutrients in the mixed layer between late winter and late summer or between surface mixed layer and the intermediate water, Midorikawa et al. (2002) and Andreev et al. (2002) estimated the annual average of new production at 100 m, which is the winter mixed layer, in the WSG (50N,

165E) and station KNOT (44°N, 155°E) to be 95 ± 7 and 105 ± 20 mg m⁻² day⁻¹, respectively. Karl *et al.* (2001) summarized the export flux at station HOT and BATS. The export fluxes measured by the seasonal drifting sediment trap experiment are estimated to be approximately 30 mg m⁻² day⁻¹ (Table 1). The export flux in the WSG is three times of those at the subtropical stations and comparable to that in the Alaskan Gyre (110 mg m⁻² day⁻¹: Sambrott and Lorenzen, 1987; Parsons and Lalli, 1988; Welschmeyer *et al.*, 1993). Therefore the high export flux is one of the prominent characteristics of the biological pump in the WSG.

5. Export ratio

Honda *et al.* (2002) estimated the transfer efficiency, which is the ratio of organic carbon flux into the deep sea to the primary production, at station KNOT. Using the annual mean of the primary production of 220 mg m⁻² day⁻¹ (Imai *et al.*, 2002) and organic carbon flux obtained by moored sediment trap, the transfer efficiency at 1000 m, 3000 m and 5000 m were estimated to be approximately 5, 3 and 2 %, respectively. These values are higher than the global average (~ 1 % at 1500 ~2000 m; Lampitt and Antia, 1997; Lutz *et al.*, 2002).

Table 1 also compares the export ratios at the bottom of the winter mixed layer at the principal ocean time-series stations. The annual average of the export ratio at station KNOT can be estimated to be approximately 0.45 or 45 % and larger than other stations. In the global scale, Pace *et al.* (1987) estimated the export ratio to be 0.13 – 0.17. Buesselar (1998) summarized the export ratio estimated by [234]Th method in the global ocean. He concluded that the export ratio in the most of oceans is less than 10 % except the high latitude zone where diatom species are pre-dominant and its export ratio is larger than 20 %. This result supports the high export ratio at station KNOT. Therefore it can be concluded that the export ratio in the WSG is high and the organic carbon assimilated by the biological activity is transported to the ocean interior more efficiently than other oceans.

6. Vertical Change Coefficient

Since Suess (1980) proposed the empirical equation for the vertical change in the carbon flux with depth, some papers have reported various equations by using results of sediment trap experiment or the mathematical simulation. Most of equations can be classified to the following two types;

$$POC_{(z)} = POC_{(100)} * \left(Z/100 \right)^{-b} \qquad (1)$$

$$POC_{(z)} = a * PP^c * Z^{-b} \qquad (2)$$

Where $POC_{(z)}$ and $POC_{(100)}$ are the particulate organic carbon fluxes at Z m and 100 m, respectively, PP is the primary production, and a, b and c are constants. The exponent b is referred as the vertical change coefficient (VCC) in this study. As the VCC increases, vertical change in the organic carbon flux becomes larger. According to Honda *et al* (1997), the VCC ranges from approximately 1.0 (Suess, 1980) to 0.57 (Pace *et al.*, 1987). Among various equations reported previously, the equation suggested by Martin *et al.* (1988) has been used most frequently and its VCC is 0.86. However, Tsunogai *et al.* (1990) suggested that VCC (they referred VCC as the vertical change index) in the high latitude area where diatom species are pre-dominant should be small because diatom produces the large aggregate particle and it should be transported vertically without a significant decomposition. This is supported by Kemp *et al.* (2000) and Smetacek (2000).

On the other hand, Berelson (2001) compiled the biological pump data obtained by U.S.JGOFS projects, and pointed out the tendency that the VCC increases with increasing the export flux. This tendency is opposite of the traditional image. Francois *et al.* (2002) compiled the sediment trap data from the global ocean. They estimated the remotely sensed primary production and the export flux using the algorithm for the primary production (Behrenfeld and Falkowski, 1997) and for the "ef-ratio" (Laws *et al.*, 2000), and consequently calculated the ratio of export flux to the carbon flux in the deep sea. Their conclusion is that the VCC is high in the area where primary production, export flux and the export ratio are high. It means that large part of organic carbon exported from the surface area decreased with the depth largely in the productive region such as the WSG. As shown in Table 1, the export flux and organic carbon flux at 3000 m at station KNOT are 100 and 6 mg m⁻² day⁻¹. Although these are higher than other stations, the VCC at station KNOT is estimated to be approximately 0.83, which is close to Martin's one and larger than Tsunogai *et al.* (1990) and Honda *et al.* (1997).

Table 1 The characteristics of the biological pump at principal time-series stations
(Honda, submitted to Journal of Oceanography)

	KNOT		OSP *4		HOT *5			BATS *5		
a Primary Production (mg m⁻² day⁻¹)	220	*1	384		416	±	178	480	±	129
b Export Flux (POC(100): mg m⁻² day⁻¹)	100	*2	110		27	±	13.9	28	±	10
c Export Ratio (b / a)	0.45		0.29		0.07	±	0.04	0.06	±	0.03
d POC flux into the deep (POC(z): mg m⁻² day⁻¹)	6.0	(3000m) *3	3.1	(3800m)	3.1	(2800m) *6		1.9	(3000m) *7	
e Transfer efficiency (d / a) (%)	2.7		0.8		0.7			0.4		
f Vertical Change Coefficient (VCC) *8	0.83		0.98		0.64			0.79		

*1 Imai *et al* . (2002)   *2 Andreev*et al* .(2002)   *3 Honda*et al.* (2002)   *4 Wong *et al* . (1999)
*5 Karl *et al* . (2002)   *6 Karl *et al* . (1996)   *7 Deuser *et al* . (1987)
*8 VCC = - log (POC $_{(z)}$ / POC $_{(100)}$) / log (z/100)

North Pacific Marginal Sea Exchanges of Carbon and Nutrients

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The continental marginal zone is among the most biogeochemically active areas of the biosphere, receives massive inputs of C, N and P through riverine inputs and exchanges large amount of these elements with the open oceans. It is the goal of this study to assess, as part of the North Pacific Synthesis Group (NPSG) of the Joint Global Ocean Flux Study (JGOFS) program, the contribution of North Pacific continental margins and seas to CO_2 sequestration and horizontal flux of nutrients across the ocean-continental margin boundary. The penetration of anthropogenic CO_2 into these marginal seas is then described.

The continental marginal shelf systems are divided into two overlapping types: the recycled systems and the export systems. The inner shelves of the Bering Sea, the Sea of Okhotsk and the East and South China Seas belong to the recycled systems, often with large riverine inputs, but the outer shelves are more export oriented. With respect to the export, often ocean dominated systems such as the Californian Shelf and Gulf of California, the northwestern American shelf, the western Canadian shelf and the shelves of the Sea of Japan, a dominant feature influencing the budgets is upwelling.

The marginal seas do serve as an important link in the global carbon cycle. Teleconnections among the marginal seas have been detected. For instance, the western part of the Kuroshio Intermediate Water originates from the nutrient-rich South China Sea intermediate water which upwells onto the East China Sea (ECS) continental shelf and contributes a large amount of nutrients to the ECS. This contribution, especially for P, is far more than the inputs from the P-deficient Yangtze and Yellow Rivers. The damming of major rivers may reduce freshwater output and the buoyancy effect on the shelves and, thus, reduce upwelling, nutrient input and productivity.

Most of the shelves and estuaries seem to show denitrification and alkalinity generation. Mass balance calculations reveal that the denitrification rate in the ECS shelf is 0.1 mol N m^{-2} yr^{-1}; whereas it is 0.042 mol N m^{-2} yr^{-1} for the entire SCS. The ECS has a new

production rate of phytoplankton as 26 $\pm$ 10 mg C m^{-2} day^{-1} and a new DOC production rate of 38 $\pm$ 15 mg C m^{-2} day^{-1} for a total of 64 $\pm$ 32 mg C m^{-2} day^{-1}, or 15% of the average primary production rate. In other words, 85% of the organic carbon produced on the shelf is regenerated. The downslope transport of modern particulate carbon is 93 $\pm$ 47 mg C m^{-2} day^{-1} of which 27% is organic. The alkalinity budget indicates that there is a substantial amount of alkalinity generation in the sediments (3.9 $\pm$ 3.9 mmol m^{-2} day^{-1}) due to anaerobic respiration such as by iron and sulfate reductions.

Most marginal seas in the North Pacific are undersaturated with respect to atmospheric CO_2 in the surface water. Further, deep marginal seas with a larger body of water, especially those with deep water formation, may be non-negligible sinks for excess CO_2. It is estimated that seawater in the marginal seas in the North Pacific alone may have taken up 1.2 $\pm$ 0.3 Gt (10^{15}g) of excess carbon, including 0.21 $\pm$ 0.05 Gt for the Bering Sea, 0.18 $\pm$ 0.08 Gt for the Sea of Okhotsk; 0.31 $\pm$ 0.05 Gt for the Sea of Japan; 0.07 $\pm$ 0.02 Gt for the East China Sea and Yellow Sea; 0.43 $\pm$ 0.1 Gt for the South China Sea; and 0.015 $\pm$ 0.005 Gt for the Gulf of California.

More importantly, high latitude marginal seas such as the Sea of Okhotsk or the Bering Sea may act as conveyer belts in exporting 0.1 $\pm$ 0.08 Gt C excess CO_2 into the North Pacific Intermediate Water per year. It is also suggested here that the upward migration of calcite and aragonite saturation horizons may also make the shelf deposits on the Bering Sea and the Sea of Okhotsk more susceptible to dissolution, which would then neutralize excess CO_2 in the near future.

As a final note, similar to what have been detected in the Black Sea or the Mediterranean Sea, the Sea of Japan has started to show responses to global warming. The temperature in the deep water has increased while the oxygen concentration decreased over the last 50 years. Anoxic condition may develop as early as 2200 AD.

The biogeochemical cycle of CO_2 in the East/Japan Sea

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Introduction

The role of ocean is very crucial in the overall biogeochemical cycle of CO_2 with its special pumping mechanisms such as solubility pump, biological pump, dynamic pump, alkalinity pump and continental shelf pump. The quantification of processes involved in the biogeochemical cycle of CO_2 is one of the most important research areas in understanding the effect of human perturbation on global climate system in recent years. The East/Japan Sea is one of a few ideal places to study these oceanic processes in small area due to its miniature-ocean characteristics. Furthermore, the East Sea has been in constant changes at least for the last 40 years: the studies of the area could provide clues on future changes in global oceans.

Materials and methods

Studies for construction overall CO_2 cycle in the East Sea have been carried out. In order to investigate the CO_2 pumping mechanisms in the East Sea, necessary CO_2 parameters (fCO_2 in marine air and surface seawater, total alkalinity and pH in water column) have been measured along with the general oceanographical parameters.

Results and discussion

The fCO_2 of surface waters varies in a range from 350 to 400 µatm in summer and from 300 to 350 µatm in winter, in general. Comparison of these concentrations with those in the atmosphere, which are fairly constant (350-370 µatm), revealed that surface seawaters in the East/Japan Sea are supersaturated in summer and are undersaturated in winter.

A model was devised for explaining the variation of fCO_2 in surface waters in time and for estimating the annual flux of CO_2 at the air-sea interface, which considers the annual variation of parameters such as the atmospheric CO_2 concentration, SST, mixed layer depth (MLD), diurnal transfer velocity (k_w) and CZCS chlorophyll data. The results show that the East Sea releases CO_2 into the atmosphere from June to September, and absorbs CO_2 during the rest of the year, from October through May with the net annual CO_2 flux at the air-sea interface of 0.045 Gt-C per year from the atmosphere into the East Sea, which is about 6 times the global average CO_2 uptake rate per unit area by the ocean.

A simple box-model (a moving-boundary box model) was also constructed to describe the current changes in dynamics observed in the East Sea and an associated geochemical model for carbon in the East Sea was attempted.

The initial results show that the dynamic pump transports 0.031 Gt-C of net carbon from the surface to the deep water in a year. Biological pump also involves 0.038 Gt-C of carbon in a year.

Other details of the models and results will be further discussed at the meeting in conjunction with the global carbon cycle.

Decadal-scale oxygen changes in the upper thermocline of the North Pacific: Ventilation or productivity change?

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Background

It has been suggested that biological processes in the subtropical North Pacific Ocean have gone through a "domain shift" in the mid 1980s in which ocean productivity changed from domination by eukaryotic organisms to one dominated by small prokaryotic organisms (Karl et al., 2001). Experimental evidence also suggests that this change was associated with an increase in the importance of nitrogen fixation as the source for the nutrient nitrogen (Karl, 1997). During a similar time interval (1970s - 1990s) it has been suggested from T and S observations and dynamical calculations in the Equatorial Pacific area that the shallow overturning circulation that couples subtropical ventilation and southward transport from the subtropical/subarctic region with northward Ekman transport from the Equator has decreased by 25 % (McPhaden and Zhang, 2002). Finally, repeated measurements of oxygen in the upper thermocline of the North Pacific Ocean indicate that there has been a significant decrease between the early 1980s and mid 1990s. This has been observed in three separate areas: the Eastern Subtropical Pacific, Emerson et al., 2001; the Western Subtropical Pacific and the Subarctic Pacific, Watanabe et al., 2001, Ono et al., 2001). The change in the Eastern Subtropical Pacific has been on the order of 10-15 μmol kg^{-1} which represents an increase in AOU of 20-25 % in this area. The reason for these changes is likely to be either oscillatory decadal-scale natural forcing or anthropogenically-induced global warming, but it is presently not possible to separate these. Repeated determination of AOU in the upper thermocline is a valuable way to monitor change in the upper ocean, but it is not clear whether these observations are caused by variations in circulation or in net biological carbon export.

Model Results

A simple model of the atmosphere and upper equatorial /subtropical North Pacific Ocean demonstrates the sensitivity of the ocean and atmosphere reservoirs of oxygen to changes in carbon export and circulation. A decrease in ocean ventilation or increase in biological carbon export by 30 – 50 % is sufficient to explain the observed changes in AOU. However, an AOU response to either of these changes implies that circulation and carbon export are uncoupled, i.e., the system does not respond as one in which a change in ventilation rate corresponds to an equivalent change in rate of nutrient supply to the surface waters by upwelling. One method of uncoupling carbon export from nutrient transport is a change in nitrogen fixation in surface waters. In this case the additional nutrients required to supply the increase in carbon export originate from the atmosphere.

Experimental Evidence

The enrichment in the N:P ratio in sediment trap particles (N:P = 23) over that found dissolved in the upper thermocline waters (N:P = 14-15) at HOT (Karl, 1997) indicates a non steady state situation with respect to nitrogen. The relatively constant C:N ratio in sediment trap particles (C:N = 7-8) between the 1980s and 1990s implies that an increase in N flux should also result in an increase in particulate C flux. A recent study of the change in preformed nitrate on the shallow isopycnals of the upper thermocline of the North Pacific (Abell and Emerson, 2002) indicates that the negative preformed nitrate previously observed in this area (Emerson and Hayward, 1995) increased between the 1980s and 1990s. This observation suggests that there has been an increase in the export of DOM or an increase in the C:N ratio of DOM during that period. These results are consistent with a change in dominance of the type of algae in the surface waters and the increase in the role of nitrogen fixation in the Subtropical Pacific. Although evidence is still circumstantial, we believe different geochemical tracers suggest that the observed AOU changes have resulted at least partly from changes in the biological pump forced by increases in nitrogen fixation.

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Increased stratification and decreased primary productivity in the western subarctic North Pacific - a 30 years retrospective study-

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The Oyashio Water locating along the western edge of the North Pacific subarctic circulation is one of the most productive regions of the world oceans. Analyzing the time series data sets collected from 1970s to 1990s in the Oyashio Water, we observed a sign of alteration of physical, chemical and biological environments of the water column in the western subarctic North Pacific.

Salinity, phosphate concentration and apparent oxygen utilization (AOU) in winter subsurface layer (on isopycnals between 26.7 and 27.2 $_\theta$) linearly increased for the 30 years, by averages of 0.0008 psu/y, 0.9 mol/l/y and 0.005 mol/kg/y, respectively. At the same time, salinity and phosphate of winter surface mixed layer decreased. Increase of density gradient between the surface and subsurface suggested that upper water column stratification be intensified to retard vertical water exchange during the period. Net community production, which was estimated from the phosphate consumption from February through August, also declined by an average of 0.51 gC/m^2/y for the decades. Average springtime diatom abundance (cell number) decreased one order of magnitude while that of wintertime more than doubled during the 30 years, consistent with the multi-decadal decreasing trend of net community production. Negative influence was also observed in secondary production. Total spring zooplankton biomass, presumably mainly composed by *Neocalanus flemingeri* decreased, and maturity timing was shifted earlier by ca. 30 days.

In the Oyashio Water, extensive phytoplankton spring bloom is reported to occur when the surface water becomes stratified to form a stable, shallow mixed layer with sufficient nutrients supplied during winter. Our results suggested that attenuation of winter vertical water mixing limited nutrient supply to the level decreasing winter-summer net community production and zooplankton biomass for these 3 decades. With the fact of doubled wintertime diatom abundance, it is speculated that earlier stabilization of the mixed layer might have gradually expedited the timing of phytoplankton bloom. The conditions might have allowed zooplankton to utilize phytoplankton from earlier timing, resulting in its apparent earlier development.

A 3-d model of the ocean carbon cycle: sensitivities to topographic mixing and the biological pump

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One objective of JGOFS is to develop coupled ocean carbon / general circulation models for use in projections of future climate change. At CCCMA we are developing and testing such a model based on the ocean general circulation model NCOM, developed at the US National Center for Atmospheric Research. Here we use this model to illustrate the general behaviour of this class of models globally and in the N. Pacific Ocean. Our implementation is on a 2° grid with 29 levels in the vertical. We have generally followed the protocols used in the OCMIP-2 Ocean Carbon Model Intercomparison Project where various properties of 13 ocean general circulation models were compared. Tests of the OGCMs in OCMIP-2 demonstrated that simulated vertical modes of circulation differ widely between the different models, many at variance with observed tracer fields (Dutay et al, 2002). This wide range of behaviour among contemporary OGCMs underscores the importance of the performance of the OCGM in transporting DIC, even before we consider addition of the biotic pumps to the solubility pump.

Our initial simulations of observed tracers, penetration of natural ^{14}C (prior to nuclear bomb testing) and CFCs from human activity, showed the vertical mixing in the model to be sluggish. An enhanced vertical mixing based on variable bottom topography, developed by Ming Li (U. Maryland), increased mixing below the upper kilometer and yielded more realistic tracer fields. In a 7500 year equilibrium simulation, the inorganic carbon module, based on that of OCMIP-2, yielded average vertical profiles for DIC similar to those of Murnane et al. (1999) – deep DIC concentrations were significantly less than observed, with a weaker vertical gradient suggesting that the sinking flux of organic particles is an important pathway for removing carbon from the surface ocean. The biotic pumps were incorporated as in OCMIP-2 – restoring surface layer phosphate concentrations to observed levels generated the export production. Results were much closer to observations than in the abiotic model – although different initial conditions, observed profiles versus a global mean value of DIC, resulted in slightly different equilibrium solutions, even after 7500 years. Maps of sea-air CO_2 exchange for both abiotic and biotic simulations are compared with maps derived from observations by T. Takahashi. Maps of DIC and TALK at different depths are compared with maps derived from observations by Goyet et al. 2000 (CDIAC-127): the biotic model replicates the clear differences between the N. Pacific and the N. Atlantic. Although this model is designed for global simulations, we show its ability to resolve the North Pacific Intermediate Water formation.

We are currently implementing a dynamic NPZD (Nutrient-Phytoplankton-Zooplankton-Detritus) model into the model (similar to that used in an isopycnic model of the North Pacific – Haigh et al. 2001) to see how it enhances the simulations over those with the nutrient-restoring biology. We are currently developing in a 1 dimensional mixed layer model, an ecosystem model with 2 size classes each of phytoplankton and zooplankton, and dynamic partitioning of export carbon into DOC and POC. When such a model is incorporated into our OGCM, we should start to be able to resolve regional patterns in biogenic carbon cycling (such as the east-west difference in the subarctic North Pacific) that have been elucidated through N. Pacific JGOFS studies.

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Export and Sequestration of Particulate Organic Carbon in the North Pacific from Inverse Modeling

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Key words: Carbon export, Sequestration, Biological pump, Inverse modeling

The oceanic distributions of oxygen, dissolved nutrients and carbon are strongly affected by the production of particulate matter and its subsequent remineralization during sinking or after deposition on the sea-floor. Dissolved nutrient data thus provide valuable information for the determination of the underlying biogeochemical rate constants using inverse modeling. Here, a global ocean circulation/biogeochemical model is presented that exploits the existing large sets of hydrographic, oxygen, nutrient, and carbon data and determines rates of export production and vertical particle fluxes compatible with the concentration data. Chlorofluorocarbon (CFC) and natural radiocarbon data are also included to help constrain the vertical and meridional overturning in the model. The model is fitted to the data by systematically varying circulation, air-sea fluxes, production and remineralization rates simultaneously. The adjoint method is applied as an efficient tool for the iterative optimization procedure, which yields simulated fields that are in very good agreement with observations. This is also true for CFC and radiocarbon fields.

Results from four different model experiments show that of the 9.5±1 Gt yr-1 of particulate organic carbon (POC) exported globally, about one fourth (2.2±0.2 Gt C yr-1) is occurring in the North Pacific, mainly in the equatorial, subtropical east and northeast Pacific. Remineralization of POC in the upper water column is efficient, and only about 6 to 10% of the exported material reach the 2000 m horizon (0.21±0.03 Gt C yr-1). The fraction of the flux that reaches the deep ocean appears to be higher in the mid- and high latitude Pacific as compared to the tropical and subtropical Pacific. Maps of carbon export and fluxes into the deep ocean and to the seafloor will be shown.

Abstracts of Posters

Simulated temporal variations of physical environments and

biogeochemical processes at the subarctic North Pacific time-series Station KNOT

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Keywords: time-series Station KNOT, ecosystem modeling, seasonality, mixed layer depth, spring diatom bloom

A marine ecosystem model based on the NEMURO (North pacific Ecosystem Model Used for Regional Oceanography; Eslinger et al., 2000; Yamanaka et al., 2002) is applied to Station KNOT (44°N, 155°E). This model has fifteen compartments including two categories of phytoplankton (diatoms and non-diatom small phytoplankton) and three categories of zooplankton (small, large and predatory zooplankton). Cycles of nitrate, silicon, calcium and carbon are simulated simultaneously. The model is driven by daily or weekly solar radiation and wind speed, and by monthly water temperature and salinity at the surface.

The simulation successfully reproduces the observed physical environments and biogeochemical processes at KNOT, e.g., large seasonal amplitudes of the temperature, nutrient concentrations and fugacity of CO_2 at the surface, and column-integrated chlorophyll-a concentration and primary production. Interannual variability also exists in each component, but is much smaller than seasonal variability at KNOT (Fujii, 2001). A couple of severe storms passes by this site each year, followed by short-term variations such as sudden decrease of the specific grazing rate on phytoplankton by zooplankton and abrupt increase of the fugacity of CO_2 at the surface (Fujii and Yamanaka, 2002).

The simulated results in 1998 and 1999 are compared with each other and also with the observed ones. The simulated temperature minimum water existing at 100 through 150m-depth is clearly found in 1999 than in 1998, consistent with the observed (Tsurushima et al., 2002). The simulated mixed layer depth (MLD) maximum reaches nearly 200m both in 1998 and 1999, but it appears twice in the mid-March and at the end of April in 1998 while it appears only once at the beginning of April in 1999. The simulated spring diatom bloom appears twice in the mid-April and at the end of May in 1998, and only once in the mid-May in 1999. The timing of the spring diatom bloom is tightly dependent upon that of the stratification of surface water, and the bloom occurs around one-month after the stratification. Strong positive correlations are found among the annual maxima of the MLD and the surface nutrient concentrations, and the annual-mean primary production at KNOT (Fujii, 2001).

For further verification and calibration of the simulated results above, long-term observed results of both physical environments and biogeochemical processes are necessary, especially for the sea surface salinity, the annual maxima of the MLD and spring diatom bloom and their timings, and zooplankton stock size.
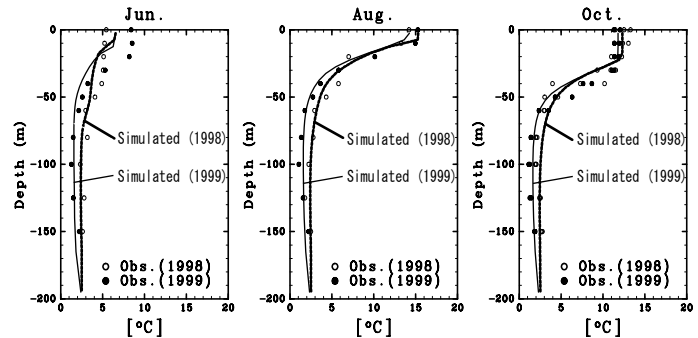

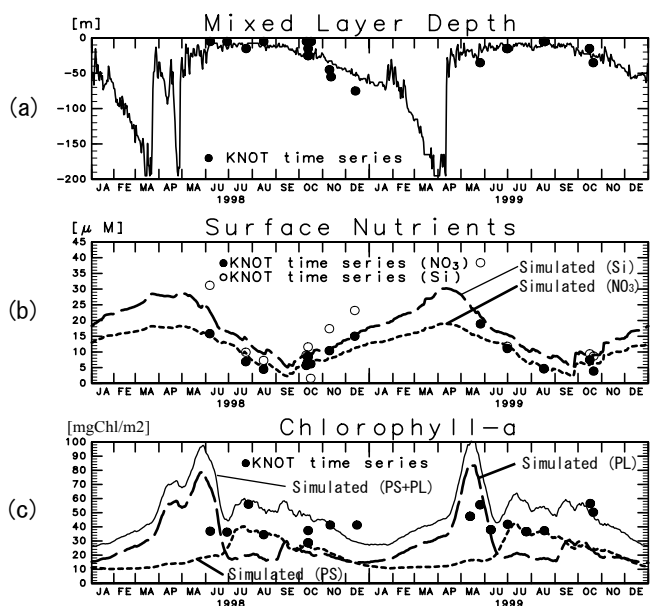Figure 1 Vertical profile of the temperature in June, August and October of 1998 and 1999.

Figure 2 (a) MLD, (b) surface nutrient concentrations and (c) column-integrated cholorophyll-a concentration in 1998 through 1999.

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Simulated Temporal Variability of Biogeochemical Processes

at the Subarctic North Pacific Time-Series Stations

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Recent studies have been revealed that oceanic biogeochemical processes, such as distributions of nutrients, total carbonate and marine ecosystem dynamics are primarily controlled by physical environments. However, it is little known how the biogeochemical processes are affected by the variations of the physical environments with longer time scale than the marine ecosystem itself has.

To tackle this issue, not only observations but the marine ecosystem modeling can be a powerful method. In this study, a vertically one-dimensional ecosystem model is applied to Stations KNOT (44°N, 155°E) and OSP (50°N, 145°W), both located in the Subarctic North Pacific. This model has fifteen compartments including two categories of phytoplankton (diatoms and non-diatom small phytoplankton) and three categories of zooplankton (small, large and predatory zooplankton). The model is driven by *in situ* solar radiation, wind speed, and water temperature and salinity at the sea surface.

Observed seasonal features of the physical environments and biogeochemical processes at each site, *i.e.,* larger seasonal variation in each compartment, deeper mixed layer depth in winter, higher surface nutrient concentrations and greater dominance of diatoms at KNOT than at OSP, are successfully reproduced by the model. Interannual variability of each compartment seems larger at OSP than at KNOT, perhaps suggesting greater sensitivity to the ENSO Event at OSP. However, more information about the biogeochemical processes, such as zooplankton stock sizes and iron concentration, is necessary for further verification of the differences in the biogeochemical processes between the two sites.

Figure. Ten-year mean results of (a) sea surface temperature, (b) mixed layer depth, (c) surface silicate concentration, (d) column-integrated stock sizes of non-diatom small phytoplankton (PS) and diatoms (PL), and (e) fugacity of CO_2 in the sea water at Stations KNOT and OSP. Observed at KNOT is from Tsurushima et al. (2002).
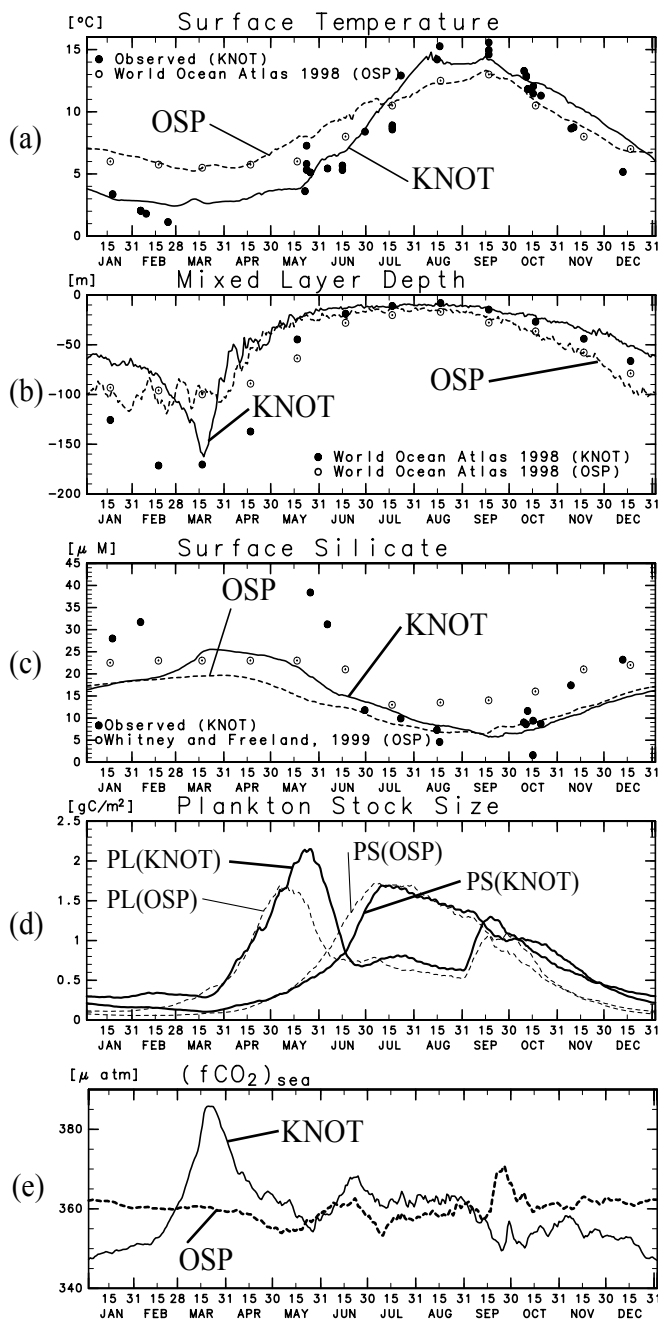
Causes and consequences of long term changes in nutrient structure and phytoplankton response in a Chinese coastal waterbody

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Long-term variation of nitrate and ammonium (N), phosphate (P), and silicate (Si) concentrations and the nutrient structure in a typical coastal waterbody, Jiaozhou Bay, China, was followed during several periods: 1961-1963 (except for Si), 1981-1986, 1991-1994 and 1997-1998. The concentration of dissolved inorganic nitrogen increased 2.4-fold from the 1960s to the 1980s and another 0.6-fold in the following decade. Phosphate increased about 1.4-fold from the 1960s to the 1980s and 2.7-fold in the early 1990s, but decreased in recent years to a level slightly higher than that in the 1960s. The concentration of Si declined continuously from the middle 1980s to the late 1990s, resulting in a 2-fold decrease overall. Thus, the nutrient structure has changed greatly in the recent past. The atomic ratio of ammonium and nitrate to phosphate (N/P) increased about 2.1-fold in the past 40 years with mean values of 9.21, 20.05, and 33.92 in the 1960s, 1980s and 1990s, respectively. The ratios of silicate to nitrate plus (Si/N) and to phosphate (Si/P) were 0.35 and 8.97 in the 1980s and 0.21 and 5.03 in 1990s, respectively; both decreased substantially.

Multiple regression analysis among nutrients and ecological and socioeconomic data from the area surrounding Jiaozhou Bay showed that the long-term variation of nitrate concentration in the seawater was basically controlled by agricultural activities (including fertilization), precipitation, population in the greater Qingdao area and drainage from Qingdao City. That of ammonium was less related to rainfall but more to anthropogenic factors such as shipping activities, population and city drainage as well as agricultural activities. Less of the variation of phosphate was explainable, but it was associated with shipping capacity, gross agricultural production, population and chemical fertilization. Si was correlated with precipitation and farming area.

Stoichiometric calculations indicated that the nutrient structure in Jiaozhou Bay has become more and more unbalanced with regard to phytoplankton requirements. There has been almost no possibility for nitrogen to be a limiting factor since the 1980s, on a large temporal and spatial scale. The probability of P limitation increased and could have occurred occasionally in autumn and summer; it was less likely to occur in spring and winter. The probability of Si-limitation increased dramatically from the 1980s to the 1990s. Seasonally, Si-limitation could have almost certainly occurred in spring and winter, although seldom in summer and autumn in the past decade.

Phytoplankton species composition in Jiaozhou Bay has changed remarkably as a consequence of the changes in nutrient structure. The firmly decreasing trend in diversity index and increasing trend in dominancy index, and the inverse correlation between the two indices clearly showed that the stability of the netplankton assemblages is decreasing. Thus, we speculate that the likelihood of certain species blooming is increasing. Since the total Chl.a level has remained roughly unchanged at around 3.55 μg/L on an annual basis for the past few decades, it is likely that smaller species have taken the niche vacated by larger species. Changes in phytoplankton size and species composition as a result of Si depletion may ultimately lead to various functional and structural changes at the system level.

Coupling of hydrographic conditions and picoplankton distribution in the East China Sea, a marginal sea of the Northwest Pacific

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Dynamics of *Synechococcus*, *Prochlorococcus*, Pico-eukaryotes and heterotrophic bacteria populations along with physical and chemical conditions in the East China Sea, a marginal sea of Northwest Pacific, were investigated in July, 1998. *Synechococcu*s, pico-eukaryotes and bacteria were ubiquitous with averaged abundance at the order of 10^4, 10^2 and 10^5 cells ml^{-1} respectively. *Prochlorococcus* was present at most locations beyond the 50m isobath at the level of 10^4 cells ml^{-1}. Responses of these picoplankters to the hydrographic conditions in the sea were recognized in both vertical and horizontal distributions. The following seemed to be typical ecological features of the marginal sea different from the situations of oceanic waters. 1) Water masses are the basic factors affecting the distribution of picoplankton. 2) Light availability played an important role in regulating picoplankton distribution patterns in the river plume. 3) *Prochlorococcus* were largely associated with oceanic water currents although they could be found in the majority of the sea; Sudden changes in cell abundance often occurred within a relatively short distance. Water temperature and salinity thresholds for *Prochlorococcus* to be present in the study period were $>26^oC$ and $>30‰$ in the surface mixed layer, and $> 16^oC$ and $>33.4‰$ in the deeper layer respectively. The *Prochlorococcus* nutrient thresholds are: TIN $<3\,µM$ and phosphate $< 0.4µM$. 4) No pronounced subsurface peaks in *Prochlorococcus* abundance depth profiles were recorded in the oceanic warm currents although *Prochlorococcus* outnumbered *Synechococcus* at least an order of magnitude there. 5) *Synechococcus* was most abundant in the coastal area associated with high nutrient level. Pico-eukaryotes usually developed very well in the front areas on the continental shelf in addition to other high abundance zones in the coastal waters. Along offshore directions, pico-eukaryotes often centered farther from the shore and deeper in water column than did *Synechococcus*. 6) Heterotrophic bacteria showed the least variation in abundance, but distinctly decreased from the coast to offshore, following an overlaid biomass pattern of pico-eukaryotes and *Synechococcus*. 7) Relationship between *Prochlorococcus* and bacteria was negative along gradients in the marginal sea.

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Ecological studies on *Prochlorococcus* in China Seas

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Prochlorococcus, a tiny oxygenic photosynthetic picoplankton with unique pigment composition has been found to be ubiquitous and abundant in the world oceans, and been recognized to be closely related to living resources and environmental issues. It has been attracting interests of marine biologists since its discovery, and field data on it over global oceans have been accumulated rapidly in the past 10 years. In China, we have studied *Prochlorococcus* for 8 years and basic ecological understandings are achieved. The presence of *Prochlorococcus* in China Seas, marginal seas of the west Pacific, was confirmed, and its distribution patterns were also brought to light. *Prochlorococcus* is very abundant in the South China Sea and the offshore regions of the East China Sea; it is seasonally present in the southeast part of the Yellow Sea and absent in the Bohai sea. Temporal and spatial variations of the abundance of *Prochlorococcus* and their affecting factors, physiological and ecological characteristics of *Prochlorococcus* and their relationships to the other groups of picoplankton, as well as the importance of *Prochlorococcus* in total biomass and possible roles in living resources and environmental problems were discussed. Physiological characteristics, genetic diversity, phylogenies and gene exploiture, of *Prochlorococcus* strains from China seas are important issues to be addressed.

Viability of bacterioplankton in the Chinese coastal waters and West Pacific

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Flow cytometry and epifluorescence microscopy were employed in determination of bacterial cells stained with 4',6-diamidino-2-phenylindol dihydrochloride (DAPI), 5-cyano-2,3-ditoyl tetrazolium chloride (CTC) and propidium iodide (PI) as total cell counts, cells with respiration viability and dead cells in the Yangtze River Estuary areas, Taiwan Strait, and the west Pacific warm pool areas. Total counts of bacterioplankton varied with environmental conditions ranging from 10^5 cells/ml to in the open ocean to 10^6 cells/ml in the coastal waters. The ratios of the respiration active cells to the total varied from 21% ~ 87%, and ratios of dead cells to total ranged from 1% ~ 48%, suggesting a considerable part of "live" but inactively respiring bacterioplankton existed in the natural sea water in the investigation areas. The possible affecting factors were discussed.
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Radiocarbon in the Okhotsk Sea and off the Kuril Islands

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In order to investigate the water exchange between the Okhotsk Sea and the North Pacific, we carried out water sampling in the southern part of the Okhotsk Sea and off the Kuril Islands in the western North Pacific in May-June, 2000 during R/V Mirai Cruise (MR00-K03). Dissolved oxygen, nutrients, carbonate parameters were measured on board and water samples for carbon isotopes ($\delta^{13}C$ and $\Delta^{14}C$) in total dissolved inorganic carbon were collected at 17 stations form surface to bottom. In laboratory, CO_2 in the water sample was stripped and converted to graphite powder for AMS radiocarbon measurement. Radiocarbon was measured by Tandem Acceletor Mass Spectrometer at JAERI, Mutsu.

Surface water temperature and CTD, XCTD, and XBT results clearly show existence of two mesoscale (100～km) anticyclonic eddies in off the Kuril Islands. Centers of these fresh and cold eddies located over the axis of the Kuril-Kamchatka bottom trench approximately. We conducted some northwest-southeast transect observations between the Okhotsk Sea and off Kuril Islands including the eddy area (Fig.1). Ratio of radiocarbon ($\Delta^{14}C$) in intermediate water of the Okhotsk Sea was larger than that of adjacent North Pacific due to rapid intrusion of the surface bomb radiocarbon into subsurface layer in the Okhotsk Sea, which indicates short ventilation time of the Okhotsk Sea intermediate water. The difference of $\Delta^{14}C$ between the Okhotsk Sea and the Pacific allows us to evaluate inflow of the Okhotsk water into the Pacific Ocean.

At the center of the southern eddy, Sta.12 on B line and just south of the Bussol' strait, Sta.7 on C line, $\Delta^{14}C$ value was larger than those around these stations in the North Pacific, suggesting a strong influence of the Okhotsk water. These imply two process of the Okhotsk water intrusion into the Pacific Ocean; intrusion into the anticyclonic eddy, which is also indicated by satelite infrared image (Fig.1), and into the coastal Oyashio current runinnig southwestwards. Additionally, using the radiocarbon data, we calculated the outflow rate of the Okhotsk water into the Pacific Ocean.
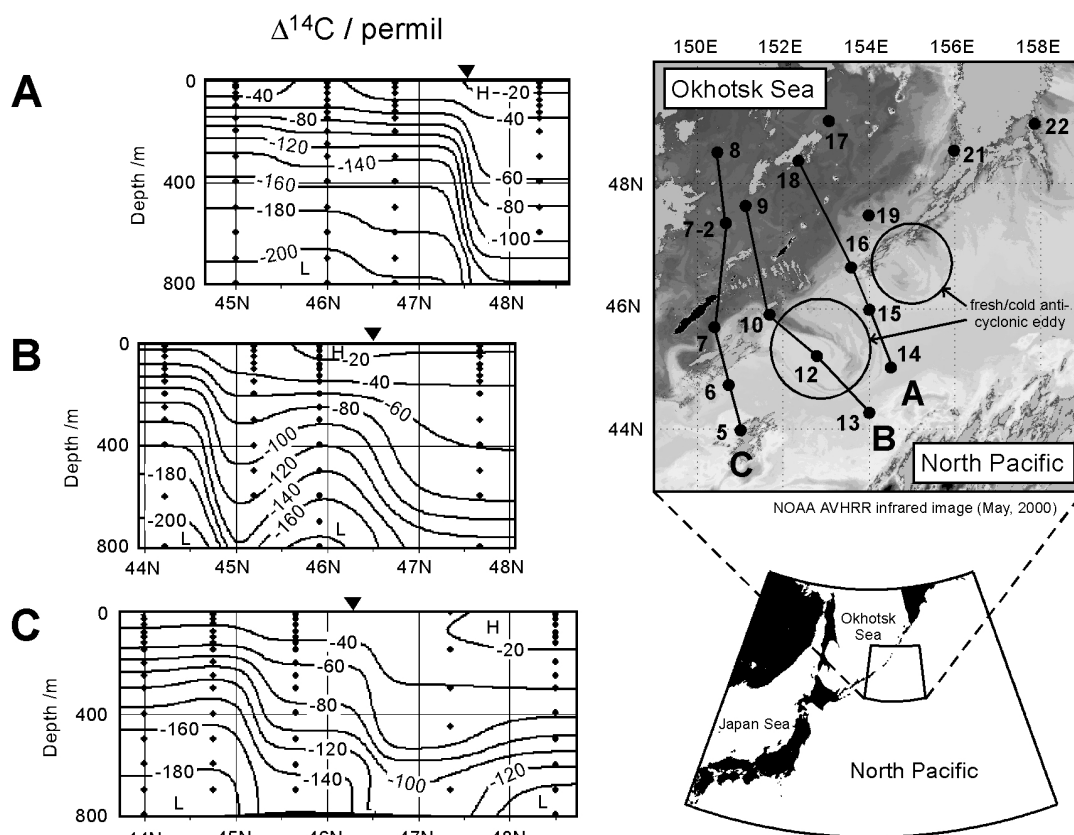

Fig.1 Distribution of radiocarbon in the southern Okhotsk Sea and off the Kuril Islands in May-June, 2000.

Evidence for climate-related variations in nitrogen fixation in the western subtropical and tropical Pacific

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Keywords : nitrogen fixation, western subtropical and tropical Pacific, climate variability

Introduction

Marine nitrogen fixation is believed to be an important source of biologically useful nitrogen to ocean surface waters, stimulating productivity of phytoplankton and so influencing the global carbon cycle. It has been suggested that enhanced nitrogen fixation during glaciations plays a large part in increasing the strength of the biological pump and thus leading to accelerate the net drawdown of atmospheric CO_2. In the modern oceans, however, the time-varying magnitudes of nitrogen fixation and its consequences are largely unknown. In this study, we have attempted to examine interdecadal variations in nitrogen fixation in the western subtropical and tropical Pacific in relation to climate events.

Data and methods

Six stations along 137 °E (30, 25, 20, 15, 10 and 5 °N) and one station at 34 °N, 141 °E where deep-water samples of nitrate and phosphate measurements were usually conducted by the Ryofu Maru during 1970-2000 were selected. The high-quality WOCE nutrient profiles observed in 1993 and 1994 at the same locations as those of the Ryofu Maru were used as reference data to compare internal consistency among the nutrient profiles. Comparisons were made based on the temperature-nutrient relationships between a pair of profiles at each station individually. The deep nutrient samples with potential temperature $\leq$ 2 °C were used for comparisons. Only the profiles with mean offsets that did not exceed 0.5 and 0.025 µmol kg^{-1} for nitrate and phosphate, respectively, were selected for subsequent analysis. We used a new quasi-conservative tracer, N^*, defined as a linear combination of nitrate (N) and phosphate (P) (Gruber and Sarmiento, 1997) to assess temporal variations in nitrogen fixation. The definition of N^* finally simplifies to

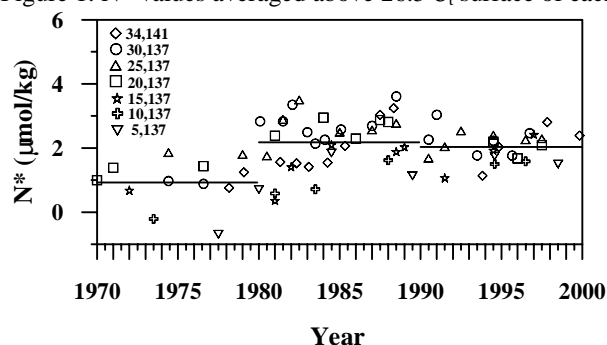$$N^* = (N\text{-}16^*P + 2.90 \text{ µmol kg}^{-1})^* 0.87,$$

where 2.90 µmol kg^{-1} is a global mean. The variability of N^* is primarily caused by the combined effect of denitrification and nitrogen fixation, since this linear combination would eliminate most of the effect of regeneration of N and P nutrients that is the most important contribution to the variability of these two tracers.

Results and discussion

In general, individual vertical profiles of N^* at all stations show positive values in shallow depths, indicating that nitrogen fixation is an important process in this region. The positive N^* values are reduced in deeper layers, a result of the decrease with depth of N-rich organic matter being remineralized. The N^* values above 26.5 σ_t surface during 1970-1999 exhibited great variations ranging from –3.73 - +6.14 µmol kg^{-1}, but positive N^* values greater than 2 µmol kg^{-1} appeared mostly in the 1980s and 1990s at all stations. In the 1980s, the N^* values of three stations located between 30 °N to 20 °N were prominently higher than those in 1970s and 1990s, with means greater than 2.9 µmol kg^{-1}. They were mainly centered around 24.8-25.6 σ_t in the core of the North Pacific Subtropical Mode Water. Time series plotted in Fig. 1 also shows that 1980-89 and 1990-99 means of N^* values averaged above 26.5 σ_t surface of each profile at all stations were twofold greater than that in the first decade. Notable changes in N^* values since 1980 were concurrent with intensification of mid-latitude westerly winds associated with the persistent and exceptionally deepened Aleutian Low pressure system. Since the late 1970s, there has also been a tendency of more frequent El Niño events and fewer La Niña events. Changes in these two modes of climate variability may result in more spring-early summer atmospheric transport of iron from the Asian desert to this region, and enhanced spring-summer stratification of the water column. Both of these conditions would tend to favor nitrogen fixation process in this region during these two decades.

Figure 1. N* values averaged above 26.5 σ_t surface of each profile for all stations. Solid bars denote means in 1970s, 1980s and 1990s, respectively.

Inventory of CO_2 and CO_2-related data in the North Pacific

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Japan Hydrographic Association

In JGOFS, many cruises for chemical and biochemical observation were conducted, and lots of data were obtained and stored to DMO. Information about data and cruises in DMO composed huge data inventory for cruises related with JGOFS in the JGOFS web site. On the other hand, data centers in PICES contries (JODC, NODC, CDIAC, MEDS, etc.) have cooperated to compile an international North Pacific data inventory for CO_2 and CO_2-related data, following a recommendation from PICES WG13/TCODE.

To make data inventory publish to all scientists, a web site of PICES CO2 Related Data Integration for the North Pacific (PICNIC) has been prepared. For the first step of PICNIC, Inventory for Japanese Chemicaloceanographic Data (IJCD), which is managed and opened at MIRC (www.mirc.jha.or.jp/IJCD/), becomes a base of data inventory, and inventories of CDIAC and IOS are compiled to IJCD inventory. Data inventory is consisted of information about cruises, which obtained the data, and is including contact address for each. Although real data is not linked directly with data inventory, almost of the data are opened and are available via data centers or scientists who are responsible about the data. PICNIC data inventory is now under construction, however, it will be opened soon from MIRC.

Trophic cascading within the planktonic food web of the Gulf of Alaska in May 2001, induced by *Neocalanus* grazing

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Three species of large calanoid copepods of the genus *Neocalanus* dominate mesozooplankton biomass throughout the entire subarctic Pacific and its marginal seas in the spring and early summer. All three species of *Neocalanus* are particle-grazing copepods that are capable of consuming both phytoplankton and microzooplankton.

As a part of the GLOBEC CGOA Process Study, we conducted grazing experiments during 3 cruises in 2001 to study the role of *Neocalanus* spp. in mediating the microbial food web structure. In these experiments, live *Neocalanus* were placed into 2-L polycabonate bottles filled with seawater and incubated on deck for 24 hours. Bottles with no *Neocalanus* added were also prepared as controls. Chlorophyll *a* concentrations in 3 size class (<5, 5-20 and >20 µm) were determined for each incubation bottle at the beginning and end of the experiments. Additional samples were preserved for enumerating the abundance of phytoplankton and microzooplankton. In this poster we show the preliminary results of 4 experiments conducted during the May cruise in the mid-shelf waters to compare the impact of *Neocalanus* grazing on phytoplankton community structure in the bloom and no-bloom conditions. The chlorophyll *a* concentration in the no bloom water was 0.3 – 0.5 µg L^{-1}, with more than 70% found in <5 µm fraction. In contrast, the chlorophyll a concentration in the water of phytoplankton bloom was higher than 3.5 µg L^{-1} and dominated by large diatoms (about 90% in >20 µm fraction).

We observed similar cascading effects after add *Neocalanus* to incubation bottles filled with high and low chlorophyll waters (Fig. 1). *Neocalanus* feed mostly on phytoplankton cells larger than 20 µm. We saw very little grazing and sometimes a positive cascading effect on the < 5 µm fraction. This can be the result of two processes. First, the retaining efficiency of *Neocalanus* may be lower to smaller particles than to larger particles. Second, it

is possible that grazing pressure of microzooplankton on the < 5 µm cells were released as a result of *Neocalanus* feeding on protozoan grazers. Such cascading effect was more enhanced in low chlorophyll water than in high chlorophyll water. Overall, *Neocalanus* spp. consumed only a small portion of phytoplankton biomass during phytoplankton bloom, but it might be able to control the abundance of large phytoplankton at no-bloom condition.
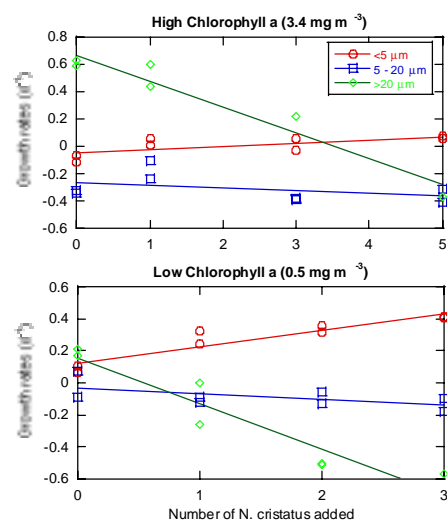

Fig. 1, The impact of *Neocalanus* grazing on the growth rates of phytoplankton in the coastal water of the Gulf of Alaska during May 2001, measured by the changes in chlorophyll-*a* concentrations in 3 size fractions after 24 h incubation. Upper: Exp.ng9 - bloom; Lower: Exp.ng10 - no bloom.

Distribution of CFC-11 in the North Pacific using a high-resolution model

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1. Introduction

Chlorofluorocarbons (CFCs) are well known tracers for investigate the ocean circulation and the anthropogenic CO2 redistribution. CFCs in the North Pacific were observed in the World Ocean Circulation Experiment (WOCE) during 1990s, etc. Watanabe et al. (1994) and Warner et al. (1996) examined the pathways and timescales of circulation and ventilation processes using the observed data. Past model studies have used CFCs to examine the ocean circulation and mixing processes in the ocean general circulation models (OGCMs). Yamanaka et al. (1998) and Ishida et al. (2001) simulated the CFCs distribution in the North Pacific. Because the models had coarse resolution, they could not examine the role of eddies and western boundary currents.

In this study, we simulate CFC-11 in a high-resolution OGCM, which resolves mesoscale eddy phenomena.

2. Model Description

We are conducting a numerical experiment to simulate CFC-11 using the high resolution OGCM developed at JAMSTEC based on the Modular Ocean Model version 2 (MOM2) of GFDL. The model has 1/4 degree resolution in both latitude and longitude and 55 vertical levels. Hellerman and Rosenstein [1983] monthly mean wind stress is used to force the model ocean. We apply heat and salt fluxes by restoring the model surface temperature and salinity to Levitus [1982] monthly data. After integrating for 30 years, the CFC-11 simulation starts with atmospheric CFC-11 in 1950. Air-Sea exchange of CFC-11 is implemented by the same formulation used in the Ocean Carbon Model Intercomparison Project (OCMIP) phase 2.

3. Results

The simulated CFC-11 distribution in the western North Pacific section (165E) is shown in Figure 1. The CFC-11 rich water around 30N corresponding to the Subtropical Mode Water and the southward spreading in the subtropical region are reproduced, though the model mode water density is slightly lower than the observation. This suggests that the thermocline circulation is simulated well in the model. The shallow invasion around 10N and deep invasion at the equator are also simulated. However, the observed deep penetration in the subarctic region is not reproduced in the model. The intermediate water formation process in the Okhotsk Sea may need to be modified in the model.
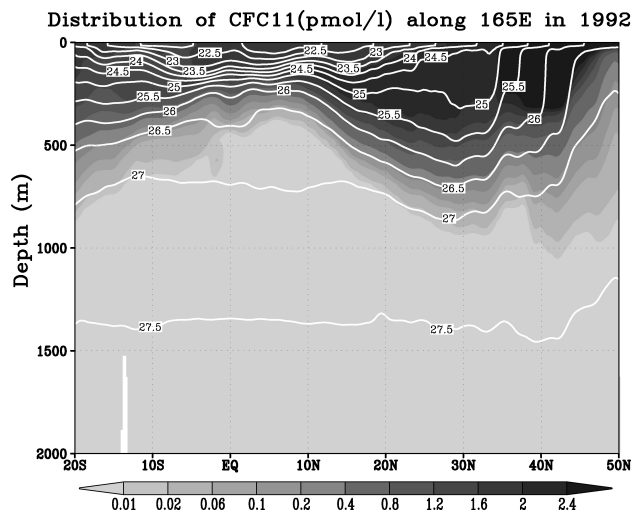

Figure1. Modeled vertical distribution of CFC-11 (pmol/L) along 165E in 1992. Contours are potential density.

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A version of NEMURO including C, N and P cycles applied to Station ALOHA: impact of the microbial food web on organic matter stoichiometries and export

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We have applied a one dimensional physical-biological model to simulate the production, recycling and export of organic matter at Station ALOHA, Hawaii. Our ecosystem model is a modified version of the NEMURO formulation developed by PICES, coupled to a one dimensional physical model. The major additions to the model are the Microbial Food Web (MFW) after *Anderson and Williams* [1999, *Global Biogeochemical Cycles*, 13(2)] carbon and phosphorous cycles, and variable stoichiometries. The stoichiometries of all living organisms are constant (although they differ significantly by the type of organism), but stoichiometries are variable for all non-living organic matter. We also include nitrogen fixation based on *Fennel et al*'s [2002, *Deep Sea Research II*, 49] model for Stn. ALOHA.

We compare our simulations to data from the Hawaii Ocean Time-series (HOT) for nutrients, dissolved organic matter (DOM), particulate nitrogen, particulate organic matter (POM) fluxes, and primary production. By employing differential rates for the remineralization of C:N:P in DOM and POM, the model can simulate the observed mean stoichiometry of POM in traps at 150 meters depth and some of the observed variations with depth in the stoichiometry of DOM. Differential remineralization (ΔR) allows the simulated ecosystem to recycle nutrients in the euphotic zone and increase production (relative to simulations without ΔR). The degradation of of carbon-rich DOM appears to be limited by the availability of nutrients (N and P), and that this may be responsible for the multi-year increase in DOC at this site as found by *Church et al* [2002, *Limnol. Oceanogr.*, 47(1)].

Where the model does poorly is in its inability to simulate the observed primary productivity (mean of 490 mg C m^{-2} d^{-1}). We present what may be a partial solution to this problem that centers on high uptake ratios of C:N by phytoplankton and especially diazotrophs. Even this, however, only allows the model to simulate about half of the measured primary production. We discuss reasons for this, including that the measurements may represent something closer to gross than net primary production, partial measurement of DOC in the experiments [*Karl et al*, 1998, *Limnol. Oceanogr.*, 43(6)] and uncertainties in measured fluxes of POM.

East-west gradients in the photosynthetic potential of phytoplankton and iron concentration in the subarctic Pacific Ocean during early summer

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key word   phytoplankton, photosynthesis, iron, trace metals

Introduction

The identification of factors controlling primary production is a key issue for a better understanding of the biogeochemical processes in high-nutrient, low-chlorophyll (HNLC) regions, where macronutrients (nitrate, phosphate, and silicate) are abundant, and phytoplankton stocks in terms of chlorophyll a concentration are relatively low (<1 mg m^{-3}) throughout the year. It is widely accepted that the NE subarctic Pacific is one of the HNLC regions, while the NW subarctic Pacific is sometimes more productive in its lower trophic levels, especially in the bloom season from late spring to early summer. Here we show that Fe can play a role in the difference.

Materials and methods

This study was conducted during a R/V *Hakuho Maru* cruise (KH-99-3), which crossed the subarctic Pacific via the Bering Sea during the early summer (June 25 – July 22) of 1999. The photochemical quantum yield (F_v/F_m) and the functional absorption cross-section (σ_{PSII}) of photosystem II (PSII) for surface phytoplankton were continuously measured using a fast repetition rate fluorometer. Concentrations of total dissolvable Fe (TD-Fe) were also determined on board ship at each sampling station. A Fe-enrichment bottle incubation experiment was carried out at Station P (50°N, 145°W) in the AG. This experiment was conducted to determine whether Fe affects photosynthetic physiology in terms of the PSII parameters, the abundance and composition of the phytoplankton assemblage. Changes over time in the concentrations of dissolved Fe and other trace metals (Mn, Ni, and Zn) stored in incubation carboys were also examined by ICP-MS or chemiluminescence for possible limitations of phytoplankton growth by these trace metals.

Results and Discussion

During the cruise, the Western Subarctic Gyre (WSG) and the Alaskan Gyre (AG), located in the NW and NE subarctic Pacific, respectively, were in HNLC conditions. Surface TD-Fe generally remained in the WSG, but was depleted (< 0.01 nM) in the AG. Nighttime F_v/F_m and σ_{PSII} in the WSG were significantly higher ($P < 0.01$) and lower ($P < 0.01$), respectively, than in the AG. (Fig. 1). Iron or nitrogen limitations generally lead to a decrease in F_v/F_m and an increase in σ_{PSII}. These results suggested that there was an east-west gradient (WSG > AG) in the photosynthetic competence of phytoplankton in the subarctic Pacific, and that the difference was probably caused by iron levels in seawater. Indeed, our iron-enrichment experiment in the AG revealed that F_v/F_m increased from 0.27 to 0.49 and σ_{PSII} decreased from 496 x 10^{-20} to 365 x 10^{-20} m^2 photon^{-1} after a 0.8 nM Fe addition. At the same time, a dramatic floristic shift from phytoflagellates to diatoms was found by phytoplankton pigment signatures. We conclude that it is Fe which may well control the photosynthetic physiology of phytoplankton, and Fe supply has a crucial impact on biota and carbon cycling in the whole subarctic Pacific.
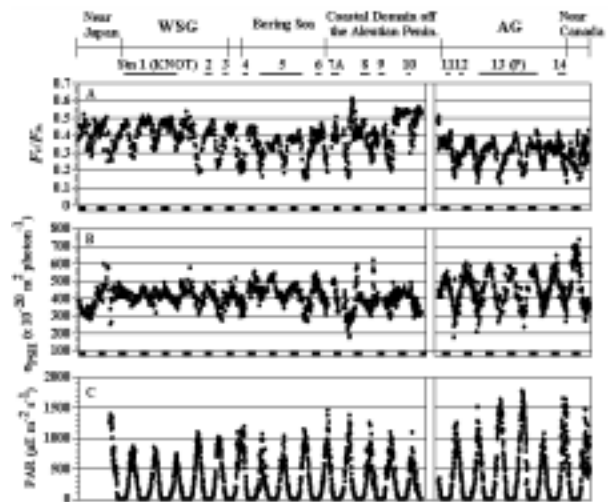

Fig. 1. Changes in (A) photochemical quantum efficiency (F_v/F_m), (B) the functional absorption cross-section (σ_{PSII}) of photosystem II and (C) photosynthetic active radiation (PAR) on deck during the underway monitoring.

Plankton community structure down to the greater depths in the western North Pacific Ocean (WEST-COSMIC)

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As part of research program "WEST-COSMIC (Western Pacific Environmental Study on CO_2 Sequestration for Mitigation of Climate Change)", vertical distribution patterns of community structure of plankton organisms were studied down to greater depths (2000-5800 m) at four stations in the western North Pacific Ocean (Table). The plankton organisms were divided into four taxonomic groups (bacteria, phytoplankton, protozooplankton, and metazooplankton) and their biomasses were quantified. Total plankton biomass in the water column was increased toward northern stations, ranging from 8,179 to 32,820 mg C m^{-2} (Table). Carbon biomass partitioning within the plankton community throughout the water column varied with station, e.g. metazooplankton dominated (47-52%) in the subarctic stations (44°N and 39°N), while bacteria (60-81%) dominated in the subtropical stations (25°N and 30°N). Decrease of biomass with depth was expressed by the equation: $Y = B_{100}(X/100)^{-b}$, where B_{100} was the biomass (mg C m^{-3}) at 100 m, Y was the biomass at given depth (X: m) and b was the depth-decreasing rate. Depth-decreasing rates (b) for which all stations data pooled was 1.421 for metazooplankton, 1.297 for phytoplankton, 0.728 for protozooplankton, and 0.673 for bacteria. Lower decreasing-rates of bacteria and protozooplankton suggest a less marked decline in the nutrients for them toward the depth of the ocean. Some other aspects of plankton community (production, ingestion, and respiration) are also discussed. For details about "WEST-COSMIC" project, see http://www.kanso.co.jp/ocean/index.html

Table Total biomass of plankton and its taxonomic composition integrated over the water column.

Station	Date	D/N	Depth (m)	Total biomass (mg C m^{-2})	Bacteria	Phyto	Proto	Meta
44°N, 155°E	19-25 Aug.	Day	0-4000	29,772	27	14	12	47
	1998	Night	0-4000	32,820	25	13	11	52
39°N, 147°E	21 Nov.	Day	0-2000	13,873	30	12	8	49
	1997	Night	-	No data	-	-	-	-
30°N, 147°E	4-6 Oct.	Day	0-5800	11,780	60	13	21	6
	1999	Night	0-5800	11,584	61	13	22	5
30°N, 147°E	15-16 Oct.	Day	0-5800	12,231	81	4	8	7
	2000	Night	0-5800	12,559	79	4	8	9
25°N, 147°E	21-22 Sep.	Day	0-4800	8,633	54	13	19	14
	1999	Night	0-4800	8,179	57	14	20	9

Preliminary results from a marine ecosystem model coupled with an Ocean General Circulation Model

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1. INTRODUCTION

To predict the effects of global warming on ecosystem dynamics and the effects of those changes in ecosystem dynamics on biogeochemical cycles and oceanic CO2 uptake, we need to develop Biogeochemical General Circulation Models (BGCMs) that represent explicitly the dynamics of oceanic ecosystems and settling particles.

During the last few years, we have been developing a one dimensional ecosystem model with Nitrogen-Silicon-Carbon cycles, which is an extension of the NEMURO model developed by PICES. We have applied this model to several Times Series Stations: HOT, Papa, KNOT, and A7 (the last two stations are in the western North Pacific and are maintained by Japanese groups) [Yamanaka et al., 2002; Fujii et al., 2002; Smith et al., 2002].

2. MODEL

Now we are incorporating this ecosystem model into a three dimensional ocean general circulation model.

Ocean General Circulation Model: We use the CCSR Ocean Component Model developed in Center for Climate System Research, University of Tokyo [Hasumi, 2000]. Horizontal resolution is one degree in both latitude and longitude, and vertical resolution is 54 levels with 5 m for all layers in the upper 100 m. Mellor-Yamada level two turbulent closure scheme is used as a mixed layer process. Atmospheric temperature and fluxes between the atmosphere and ocean surface according to the Ocean Model Intercomparison Project (OMIP) procedures is used as boundary conditions.

Biogeochemical Processes: We divide phyto-plankton and zooplankton into two and three categories, respectively: large phytoplankton (PL), small phytoplankton (PS), large zooplankton (ZL), small zooplankton (ZS) and predatory zooplankton (ZP). PL represents diatoms that make siliceous shells. PS represents the other phytoplankton than diatoms (*e.g.*, flagellates). ZS represents the others (*e.g.*, zooflagellates, ciliates, amphipods). A fraction of PS and ZS are regarded as calcarious-shelled cocolithophorids and foraminifera, respectively. ZL represents copepods with seasonally vertical migration (ascending to shallower depths in the spring, growing while grazing other plankton at shallow depth, and returning to deeper waters in the fall) except the equatorial region. Predatory zooplankton (ZP) represents zooplankton such as euphausiids that feed on other plankton.

The model includes three nutrients and three kinds of settling particles: nitrate, ammonium, and silicate, particulate organic matter, opal, and calcium carbonate. Dissolved organic matter is also included in the model. We also calculate total alkalinity, total carbon dioxide and partial pressure of carbon dioxide.

3. RESULTS

In our preliminary results, unrealistic high primary production in the equatorial regions is obtained, though the model results in the other regions agree roughly with observations. We still need to tune the biological parameters (at present, we use global constants tuned the optimal values for the subarctic Pacific for each biological parameters): introducing temperature dependence and iron-limitation. For the equatorial regions, we also need to improve physics in our model (at present, unrealistic deep mixed layer depth is obtained due to one degree resolution in longitude).

Biological processes and silicon/nitrogen ratio relevant to the spring diatom bloom

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Diatom plays important roles not only in the marine ecosystem but also in the biogeochemical cycle. The spring diatom bloom is an event that the biomass of diatom explosively increases in the spring. The object of this study is to explore what process controls the spring diatom bloom and affects in the biogeochemical cycle.

We have developed a one-dimensional ecosystem model which has 15 compartments including two categories of phytoplankton (diatom and non-diatom small phytoplankton) and three categories of zooplankton (small, large and predatory zooplankton) [Yamanaka et al., 2002] to understand the biological and chemical interactions of organisms in the ecosystem. We have applied this model to the station A-7 (41° 30'N, 145° 30'E) in the western North Pacific.

We have discussed the mechanism of the spring diatom bloom [Yoshie et al., 2002]. We have clarified the processes controlling the spring diatom bloom from the analysis of the plankton dynamics. Especially, the dilution effect by the winter deep mixing on the photosynthesis and the grazing essentially affects the spring diatom bloom. When the mixed layer depth deepens, the biomass of diatom starts increasing, although its concentration decreases because of the dilution by the winter mixing. The decrease of grazing pressure of diatoms is significantly larger than the decrease of photosynthesis of diatoms. The dilution effect on the grazing rate is stronger than that on the production rate, because the grazing rate depends on the concentrations of both diatom and grazer, whereas the production rate depends only concentration of diatoms.
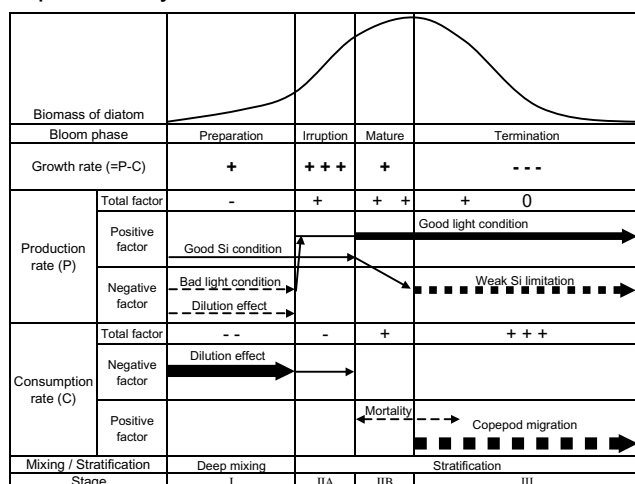
We have also focused on the silicon to nitrogen (Si/N) ratios in the ecosystem [Yoshie and Yamanaka, in preparation]. Time variations of the Si/N ratio in the spring diatom bloom results from the difference between silicon and nitrogen cycles in the ecosystem. Especially, the regeneration of nitrogen through ammonia is most important. The Si/N ratio of uptake by total phytoplanktons (without consideration of ammonium uptake) (Si/Nup$_{NO3}$) is determined by the mean weighted by the production rates of diatom and the other phytoplanktons, and by the contribution of ammonium uptake to total uptake of nitrogen of diatom. The Si/N ratio of sinking particle (Si/Nsink) is determined by the effects that the biogenic silica (Opal) is quickly egested as the fecal pellet without metabolizing of zooplankton and that the particulate organic nitrogen decomposes quicker than opal. The Si/N ratio estimated by the decreases of silicate and nitrate concentrations in the water column (Si/Nwater) is determined by the effects that the nitrification compensates the decrease of nitrate concentration due to uptake by the organisms. We have found that those Si/N ratios in the ecosystem have seasonal variations and different values each other, even if the Si/N ratio in the comparison of diatom is a constant. In the case using the diatom's stress condition based on the specific production rate of diatom, the stress affects the Si/N ratios in the ecosystem. Under the stress condition, the effect of diatom's sinking on the Si/N ratios in the ecosystem cancels out that of increase of diatom's Si/N composition rate.
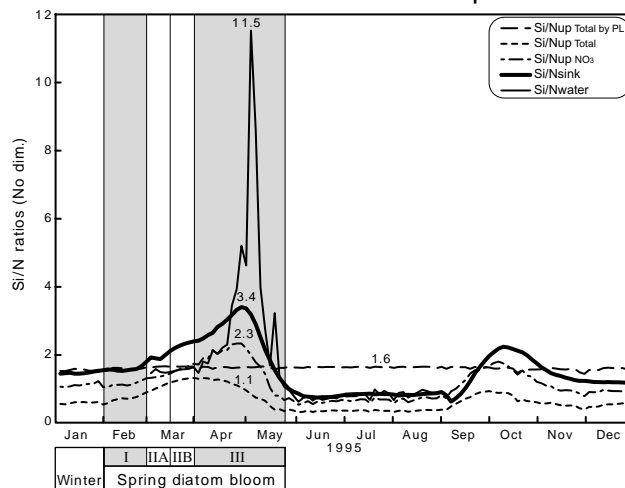
		Preparation	Irruption	Mature	Termination
Biomass of diatom					
Bloom phase		Preparation	Irruption	Mature	Termination
Growth rate (=P-C)		+	+ + +	+	- - -
Production rate (P)	Total factor	-	+	+ +	+ 0
	Positive factor	Good Si condition		Good light condition	
	Negative factor	Bad light condition / Dilution effect		Weak Si limitation	
Consumption rate (C)	Total factor	- -	-	+	+ + +
	Negative factor	Dilution effect			
	Positive factor			Mortality	Copepod migration
Mixing / Stratification		Deep mixing		Stratification	
Stage		I	IIA	IIB	III

Figure 1. Schematic view of the spring diatom bloom

Figure 2. The time series of the Si/N ratios in the ecosystem from Jan. 1 to Dec. 31 in 1995

A study of seasonal variations in nitrogen isotope ratio of sinking particles using a marine ecosystem model

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and Takeshi Nakatsuka (Inst. Low Tem. Sci., Hokkaido Univ.)
Keywords: Nitrogen isotopes, Ecosystem model, Sediment traps, Sea of Okhotsk

To quantitatively investigate the processes controlling the nitrogen isotope ratio (δ^{15}N) of sinking particles, we have developed an ecosystem model for nitrogen cycling including the two nitrogen isotopes (^{14}N and ^{15}N). This model has six compartments: phytoplankton, zooplankton, particulate organic nitrogen, dissolved organic nitrogen, nitrate and ammonium. We have applied this model to the ecosystem in the Sea of Okhotsk, and successfully reproduced the seasonal variations in δ^{15}N and fluxes of sinking particles obtained from sediment trap experiments.

The fluxes of sinking particles show two peaks of phytoplankton blooms in spring and autumn, which are common features at high latitudes. The δ^{15}N and fluxes of sinking particles from spring to autumn show an inverse relationship. This is caused by the preferential uptake of ^{14}NO$_3^-$ by phytoplankton, which increases the δ^{15}N of surface nitrate as surface nutrients are depleted and fluxes of sinking particles decrease. However, from late autumn to winter, the δ^{15}N of sinking particles increases, although the δ^{15}N of surface nitrate must decrease associated with convective mixing. In our model, the increase in δ^{15}N of ammonium by nitrification in winter contributes about 60% to a δ^{15}N increase in sinking particles from autumn to winter. We attribute the remaining 40% to the contribution of zooplankton, which produce particles with relatively high δ^{15}N to the sinking particles by previous studies.
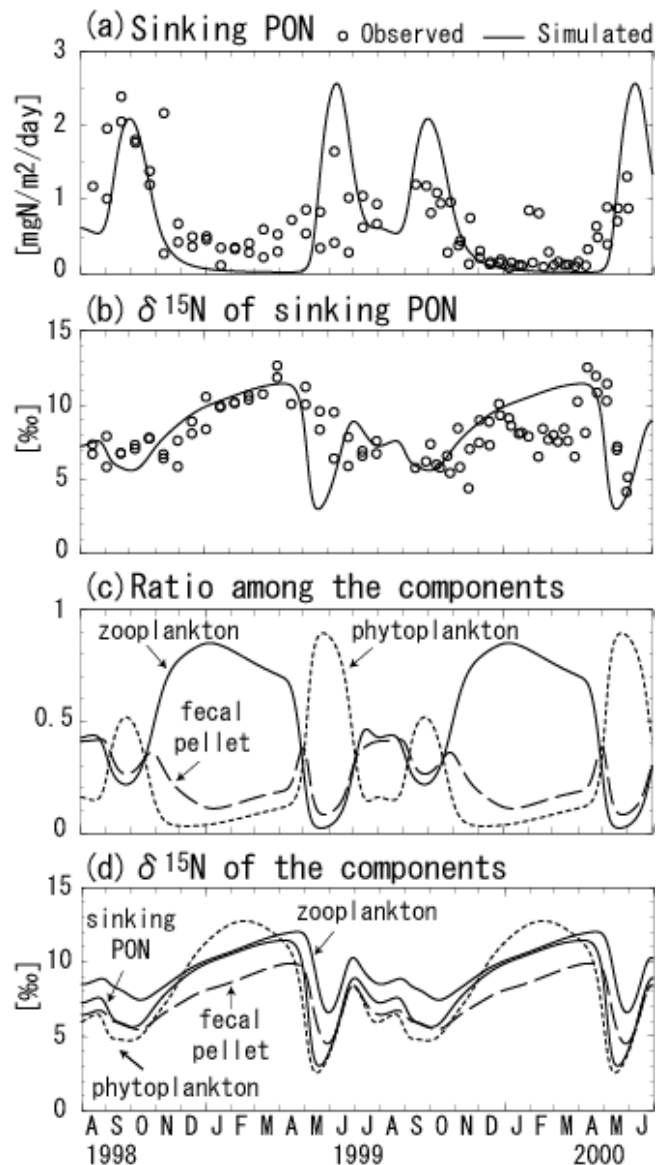

Fig. 1   The δ^{15}N and fluxes of sinking particles.

Interdecadal Variation of the Transition Zone Chlorophyll Front, A Physical-Biological Model Simulation between 1960 and 1990

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Abstract

The Transition Zone Chlorophyll Front (TZCF) separates the low chlorophyll subtropical gyres and the high chlorophyll subarctic gyres in the Pacific Ocean. The interdecadal climate variability affects marine ecosystems in both subtropical and subarctic gyres, consequently the position of the TZCF. A three-dimensional physical-biological model has been used to study interdecadal variation of the TZCF using a retrospective analysis of a 30-year (1960-1990) model simulation. The physical-biological model is forced with the monthly mean heat flux and surface wind stress from the Comprehensive Ocean Atmosphere Data Set.

The modeled position of the TZCF, operationally defined as the isopleth of 0.2 mg/m^3 chlorophyll, is located between 25°N and 27°N in the central North Pacific during the winter and between 33°N and 35°N during the summer, which agrees with the seasonal migration patterns of the TZCF detected with SeaWiFS. The modeled winter MLD shows the largest increase between 30°N and 40°N in the central North Pacific (150°E to 180°), with a value of 40-60% higher (deeper mixed layer) during 1979-90 relative to 1964-75 values. In the subarctic gyre in both northeast (Ocean Station Papa, OSP) and northwest Pacific (Oyashio region), the modeled winter MLD decreases by about 20% during the period of 1979-90 relative to 1964-75 levels. The winter Ekman pumping velocity difference between 1979-90 and 1964-75 shows the largest increase is located between 30°N and 45°N in the central and eastern North Pacific (180 to 150°W). In the subarctic northeast Pacific region including the Gulf of Alaska, the winter Ekman pumping velocity decreases during the period of 1979-90, but its value increases in the northwest Pacific (Oyashio region) after 1976-77 climatic shift. The modeled winter surface nitrate difference between 1979-90 and 1964-75 shows increase in the latitudinal band of 30°N and 45°N from the west to the east (135°E-135°W), the modeled nitrate concentration is about 10 to 50% higher in general during the period of 1979-90 relative to 1964-75 values depending upon location. The increase of the winter surface nitrate concentration during 1979-90 is caused by a combination of the winter MLD increase and the winter Ekman pumping enhancement after 1976-77 climatic shift. The modeled nitrate concentration increase after 1976-77 lead to the primary productivity increase in the central North Pacific (30°N-40°N and 180°-140°W). Enhanced primary productivity after the 1976-77 climatic shift contributes higher phytoplankton biomass and therefore elevates chlorophyll level in the central North Pacific. Increase in the modeled chlorophyll expend the transitional zone and push the TZCF equatorward.